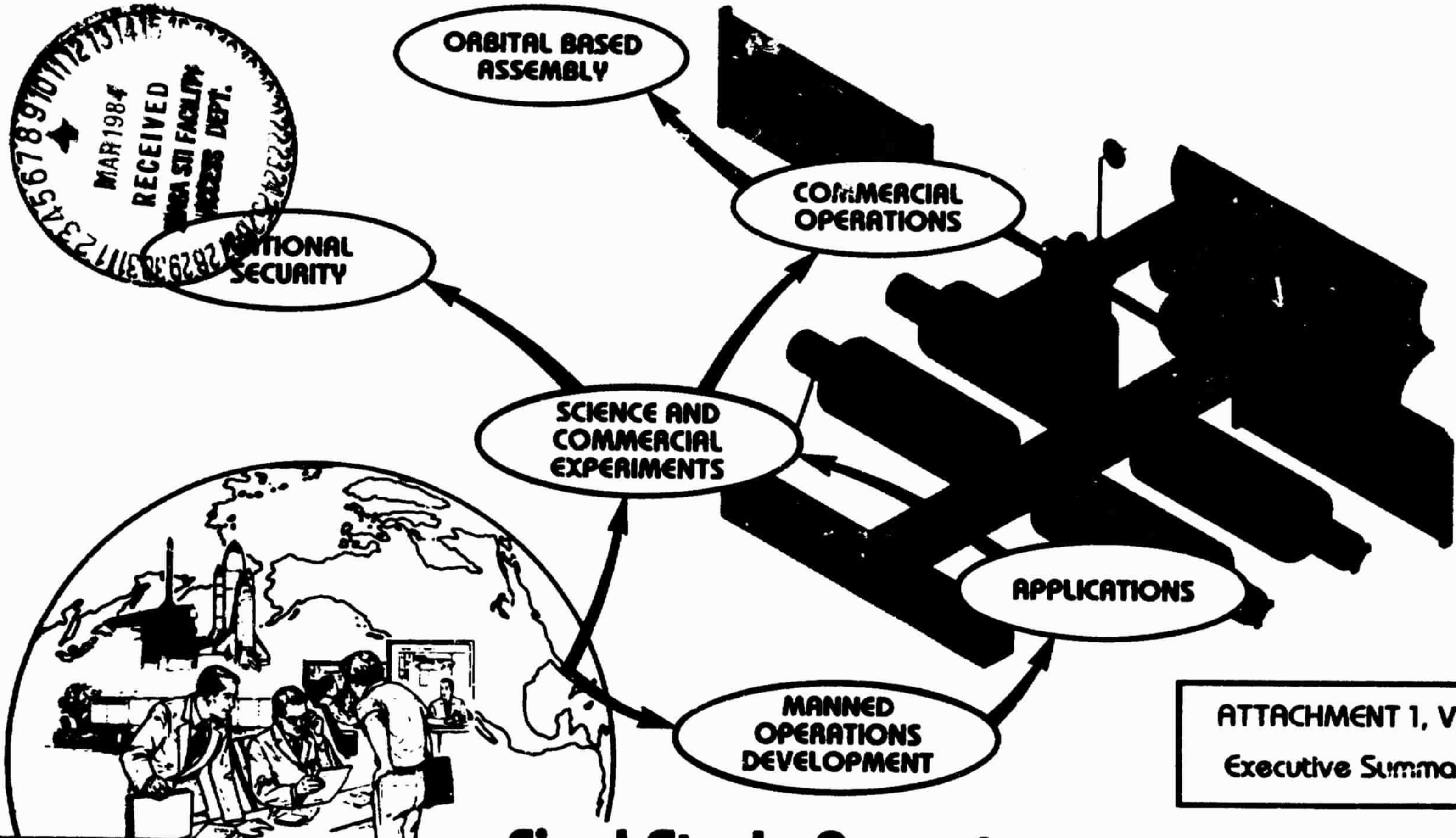
(NASA-CR-173337) SPACE STATION NEEDS, ATTRIBUTES AND ARCHITECTURAL OPTIONS. VOLUME 1, ATTACHMENT 1: EXECUTIVE SUMMARY NASA Final Study Report (Lockheed Missiles and Space Co.) 281 p HC A13/MF A01 CSCL 22B G3/15

N84-18293

Unclas 12334

LMSC-D889718
22 APRIL 1983

NASA Space Station Needs, Attributes and Architectural Options



ATTACHMENT 1, VOLUME I
Executive Summary NASA

Final Study Report

Lockheed Missiles & Space Company, Inc.

LMSC-D889718
22 APRIL 1983

NASA

Space Station Needs, Attributes, and Architectural Options

FINAL STUDY REPORT

CONTRACT NAS3684
22 APRIL 1983

ATTACHMENT 1, VOLUME I

Executive Summary NASA

Prepared For **NASA Headquarters**
Washington, D.C.

Prepared By *Lockheed Missiles & Space Company, Inc.*
Sunnyvale, California 94088

FINAL STUDY REPORT CONTENTS

SPACE STATION PROGRAMS

STUDY OVERVIEW

Lockheed

STUDY OBJECTIVES

Now that the space shuttle is operational, NASA has to be prepared for the next logical step, "Space Station", which will establish man's continuous presence in space. The objectives for this study were formulated to attain the above goal by giving the space station study as broad a support base as possible. Lockheed is dedicated to work with NASA for the attainment of these objectives, throughout the study contract and beyond.

Further objectives of this study were for each contractor to use his own enginuity with a minimum of technical direction from NASA. The reasoning here was to stay away from existing designs, to resist doing detailed design work, but instead to define the fundamental space station system architecture.

Lockheed started from the basic level of setting requirements. Obtaining requirements by means of the actions stipulated in our alignment plan was extremely difficult, which confirmed our initial fears. Other methods (scenarios) were used to trigger potential user inputs which resulted in coverage of all issues with guarded success.

When this study ends a large number of new potential space station users will have been identified. A very strong U. S. national Security Operational Mission has been identified and studied in some depth.

NASA should not let this new found enthusiasm die on the vine. Continuous effort is required to translate these needs into hard requirements.

SPACE STATION PROGRAMS

STUDY OBJECTIVES

- TO CREATE BROAD BASED USER SUPPORT FOR THE SPACE STATION
- TO GAGE THE "POTENTIAL USER" READINESS FOR SPACE STATION START-UP IN FIVE AREAS
  - (1) SCIENCE
  - (2) APPLICATIONS
  - (3) COMMERCIAL
  - (4) U.S. NATIONAL SECURITY
  - (5) SPACE OPERATIONS
- TO PROVIDE POTENTIAL USERS WITH KNOWLEDGE OF SERVICES AND POTENTIAL BENEFITS OF A SPACE STATION SYSTEM
- TO IDENTIFY AND TO DEFINE USER REQUIREMENTS THAT WILL DRIVE THE SPACE STATION DESIGN
- TO IDENTIFY AND TO CHARACTERIZE SPACE STATION SYSTEM ATTRIBUTES AND CAPABILITIES TO MEET USER REQUIREMENTS
- TO ESTABLISH EVOLUTIONARY ARCHITECTURE FOR DEVELOPMENT, INTEGRATION AND OPERATION OF A SPACE STATION SYSTEM
- TO ESTABLISH COST ESTIMATES FOR EVOLUTIONARY SPACE STATION CONCEPTS, AND SOCIO/ECONOMIC BENEFITS

SPACE STATION EVOLUTION

Following the establishment of mission support requirements based on user contacts, mission implementation concepts were formulated for a four phase space station evolution. A modest capability was planned for 1990 with an expanded capability station in the late 1990's. An overview of this phasing is shown in the the adjacent chart. Subsequent charts define each phase, the details of which provided ground rules for completing tasks 2 and 3.

The evolution was developed within guidelines that required staying rather general in trade studies and avoiding point design while still driving towards detailed user needs. General needs may be summarized as lower inclinations, LEO, general purpose initial station capability (due in part to a lack of specific knowledge of space environments), adaptability to an unknown real future, and a user friendly station.

SPACE STATION PROGRAMS

SPACE STATION EVOLUTION

SPACE STATION—PHASE IV

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1988	R&D OPERATIONS	EXPANDED C^3 I	NUCLEAR POWER	MAY INCLUDE MAIN STATIONS IN
		ESCAPE CAPSULE	HIGH THRUST PROPULSION	CRITICAL ORBITS WITH SMALL OUTPOST
2000	C & C	LARGE CREW	SHIELDING	STATION EQUALLY SPACED
		HARDENING	CO-LOCATED DEFENSE	

SPACE STATION—PHASE III

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1995	INSTALLING & SERVICING	CAPABILITY TO TRANSFER	MAIN LEO STATION &	MAINTENANCE SCHEDULE WILL ESTABLISH
				...ITMENT. PROBABLY
				VISITS
				...E TANK FARM OR
				...ARGE LASER BATTLE
				...E VOLUME FOR SPARES?
				...IREMENT FOR LOCAL
				...ISPORTATION?
				...AND RANGE WITH
				...F FUEL?

SPACE STATION—PHASE II

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1993	SATELLITE SERVICING	DOCKING FOR:	ENCLOSED OR OPEN	HOW MUCH EVA CAN BE EXPECTED -
		SPACECRAFT	HANGERS & MORE PLATFORMS	WILL ENCLOSED MORE STATIONS BE
	OTV SERVICING	OTV		REQUIRED?
1994		TMS	EXTENT OF TESTING OF OTV/	

SPACE STATION—PHASE I

TIME	MISSION	SPACE STATION SERVICES	IMPACTS AND OPTIONS	COMMENTS AND CONSIDERATIONS
1990	SCIENCE & APPLICATION EXPERIMENTS	HABITAT	NUCLEAR OR SOLAR POWER	MUST BE CAPABLE OF USING EITHER SOL OR NUC PERHAPS TIME PHASED
		POWER	SEPARATE MANNED LAB	INTERNAL LAUNCH SENSOR VIEWING/PORTS ACCESS TO SPACE
	DOD RE D			
	COMMERCIAL PROCESSING EXPERIMENTS	EXPERIMENT SUPPORT	FIXED EXPERIMENT PALLET	MAN TENDED
		COMMUNICATIONS	ISOLATED EXPERIMENT PALLET	ISOLATED PALLET REQUIREMENTS PROBABLY
	OPERATIONAL EXPERIENCE			SATISFIES FOR PHASE I BY LOOSELY TETHERED PALLET
		ENVIRONMENT	SEPARATE OR INTEGRAL	USE OF ESA SPACE LAB EURECA
			C & DH CAPSULE	HOW CAN ELECTRONICS BE UPDATED OR REPAIRED - IN ORBIT OR GROUND
		ZERO G		
		LOW CONTAMINATION	EMERGENCY SHELTER	HOW LONG? SHOULD IT HAVE A RE-ENTRY CAPABILITY - (SHUTTLE DISASTER)

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

SPACE STATION EVOLUTION PHASES

Evolution of the space station system from an initial capability in 1990 to a significantly expanded capability ten years later has been divided into four generalized phases which characterize what the station system is capable of doing at points in time. Initially the station will begin with a single shuttle launch which will provide enough hardware to implement an R&D in space facility that can accomodate civil and DoD needs. This facility will be further enhanced by additional launches. A second phase adds propulsive capability by means of TMS and/or OTV's which allows satellite servicing and our orbit assembly of larger structures to commence. A third phase expands the stations capability to handle deployment, retrieval and servicing of satellites in virtually all low or medium orbit locations. The fourth phase, near the end of the decade expands both commercial and DoD capabilities. It could then include rescue vehicles and possibly multiple stations.

Evolution of the system though the four phases shown here will be accomplished though several steps of station implementation. Later in the presentation evolutionary steps are referred to in Task 2 discussions of architectural development. Those steps, many in number, show how station implementation meets the capabilities of the four evolutionary station phases.

SPACE STATION PROGRAMS

EVOLUTION PHASES

PHASE I

R&D LABORATORY - ACCOMODATES DoD AND COMMERCIAL USER AND SCIENCE EXPERIMENTS

PHASE II

ADDS OTV AND TMS CAPABILITY WHICH ALLOWS SUPPORT TO FREE FLYERS. SATELLITE SERVICING AND ASSEMBLY IN ORBIT

PHASE III

EXPANDS DEPLOYMENT AND SERVICING TO LARGE MULTI-SATELLITE SYSTEMS IN ALL LEO AND HEO APPLICATIONS

PHASE IV

EXPANDS COMMERCIAL, DoD OPERATIONS (C^2) AND RESCUE VEHICLE. COULD BE MULTIPLE STATIONS

USER CONTACT PLAN

The Lockheed approach to develop users needs was to meet with the users on a personal basis or in small groups. This technique tended to favor a more relaxed meeting and seemed to result in a good "give and take" dialog. Though we have covered all mission categories extensively, we placed extra emphasis on the Commercial and National Security areas and, in accord with NASA desires we used NASA contacts for expanding our data base in the scientific field. Extensive contacts were also made with foreign companies and agencies.

SPACE STATION PROGRAMS

USER CONTACT PLAN

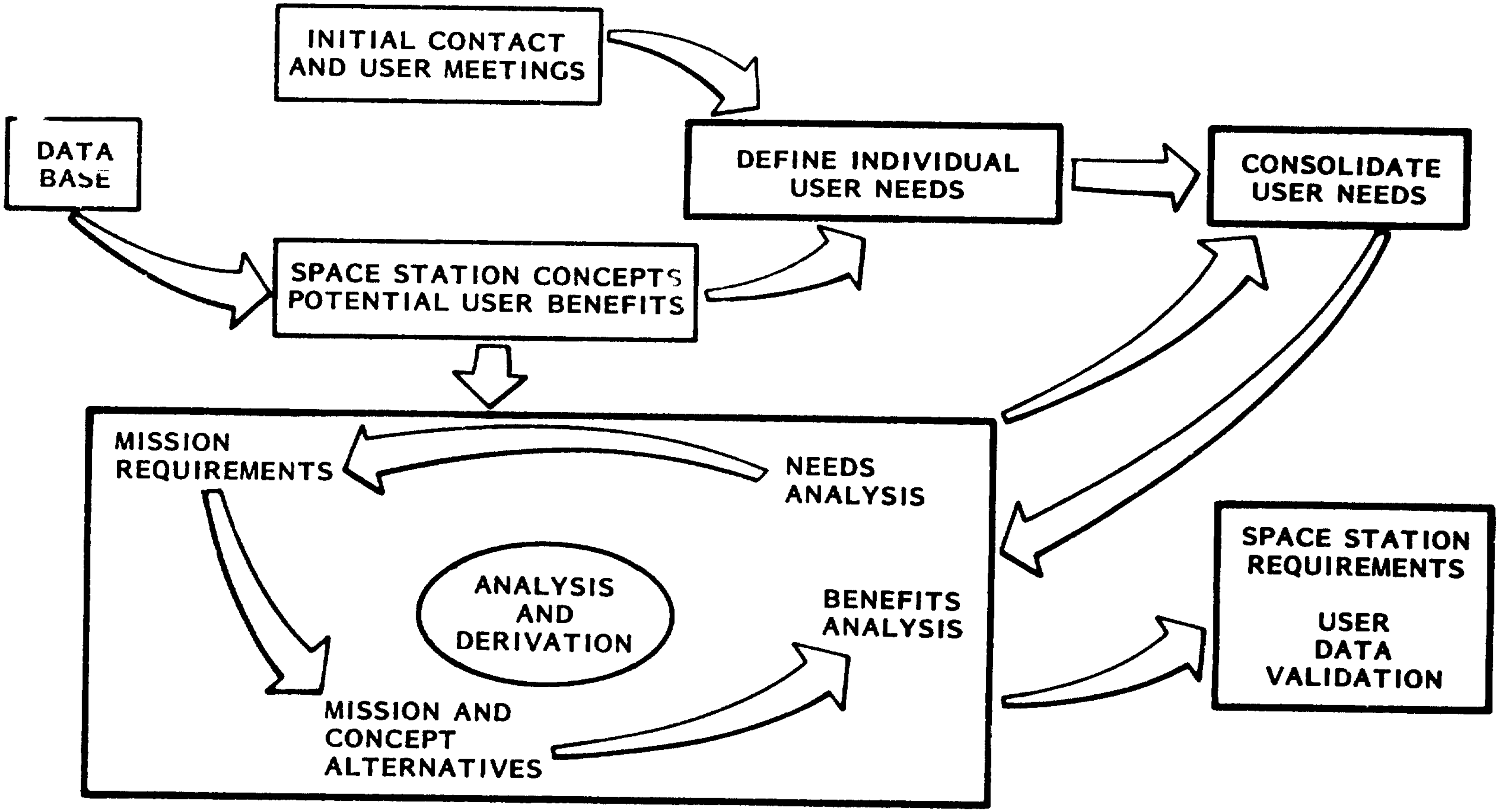
- SMALL GROUP APPROACH - DISCIPLINE ORIENTED
- FOLLOW-UP CONTACT CONCEPT
- EMPHASIZED NATIONAL SECURITY AND COMMERCIAL
- SCIENCE CONTACTS (PRIMARILY THROUGH NASA)
- APPLICATIONS (OVERLAPPED WITH COMMERCIAL AND SCIENCE)
- OPERATIONS/LOGISTICS SUPPORT INTEGRAL TO ALL CATEGORIES
- FOREIGN CONTACTS (EXPRESSED CONSIDERABLE INTEREST)
- INFORMATION FROM CONTACTS ENTERED INTO COMPUTERIZED DATABASE
- SEMINAR TO EDUCATE HIGH LEVEL COMMERCIAL INTERESTS

USER INTERACTION

The first study task, Mission Requirements, consisted of three main subtasks - user contacts and meetings, defining user needs, and consolidating those needs into mission requirements.

After reviewing the NASA data base for potential Space Station missions, initial contacts and meetings were held with potential station users or experimentors. Individual user needs were slower in developing than we desired, therefore, we decided to develop specific space station scenarios and concepts as a means of confirming and solidifying user needs. As these needs were defined, the third subtask of consolidating needs was accomplished and provided an input to the analysis and derivation effort. These analyses had an output consisting of architectural concepts and cost and benefit analyses. The output of this effort was in turn reviewed with users to validate the concepts and conclusions derived during the study.

USER INTERACTION



PRECEDING PAGE BLANK NOT FILMED

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN

1.2 SCIENCE AND APPLICATIONS

— PHYSICAL SCIENCES

— LIFE SCIENCES

1.3 COMMERCIAL

1.4 U.S. NATIONAL SECURITY

1.5 SPACE OPERATIONS

1.6 REQUIREMENTS FROM USER NEEDS

1.7 FOREIGN CONTACTS

Lockheed

PAGE 12 INTENTIONALLY BLANK

SUMMARY OF USER CONTACTS AND VISITS

A breakdown of the 323 individuals visited, out of over 450 contacted, is shown by area - Science and Application, Commercial, National Security, and International. The number of people visited more than once is also shown.

SUMMARY OF USER CONTACTS AND VISITS

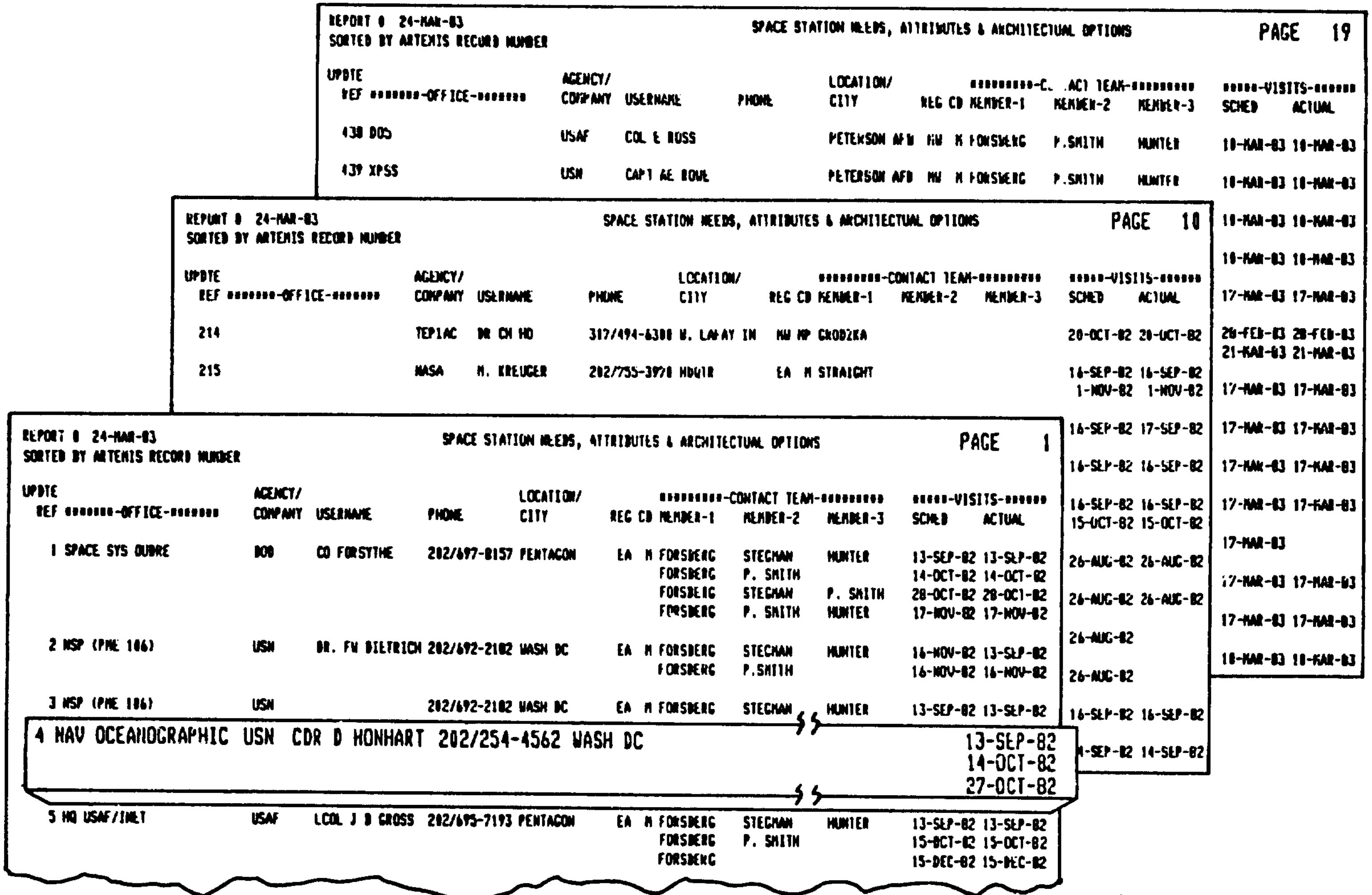
• SCIENCE AND APPLICATION - LIFE SCIENCES - PHYSICAL SCIENCES - TECHNOLOGY	-	117 CONTACTS, 14 MULTIPLE VISITS
• COMMERCIAL - MEDICAL - MATERIAL PROCESSING	-	98 CONTACTS, 13 MULTIPLE VISITS
• US NATIONAL SECURITY	-	68 CONTACTS, 22 MULTIPLE VISITS
• INTERNATIONAL	-	43 CONTACTS, 8 MULTIPLE VISITS
TOTAL CONTACTS	-	326, INCLUDING 57 CONTACTED MORE THAN ONCE

USER ALIGNMENT PLAN CONTACT LIST

A sample of the contact list for the User Alignment Plan is shown in the adjacent chart. Over 450 people were contacted and 323 of them were actually visited. The particular computer program used to maintain our contact listing can be used to sort by agency visited, contactor, date of visit, area of the country, or general area of interest. This proved to be a valuable tool in coordinating trips, meetings and telephone contacts.

SPACE STATION PROGRAMS

USER ALIGNMENT PLAN CONTACT LIST



REPORT 0 24-MAR-83
SORTED BY ARTEMIS RECORD NUMBER

SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

PAGE 19

UPDTE REF	OFFICE	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD	CONTACT TEAM MEMBER-1	MEMBER-2	MEMBER-3	VISITS SCHED	ACTUAL
438	DOD	USAF	COL E ROSS		PETERSON AFB	NW	M FORSBERG	P.SMITH	HUNTER	10-MAR-83	10-MAR-83
439	XPSS	USN	CAPT AE ROWE		PETERSON AFB	NW	M FORSBERG	P.SMITH	HUNTER	10-MAR-83	10-MAR-83
										10-MAR-83	10-MAR-83
										10-MAR-83	10-MAR-83
										17-MAR-83	17-MAR-83
										28-FEB-83 21-MAR-83	28-FEB-83 21-MAR-83
										17-MAR-83	17-MAR-83
										17-MAR-83	17-MAR-83
										17-MAR-83	17-MAR-83
										17-MAR-83	17-MAR-83
										17-MAR-83	
										17-MAR-83	17-MAR-83
										17-MAR-83	17-MAR-83
										10-MAR-83	10-MAR-83

REPORT 0 24-MAR-83
SORTED BY ARTEMIS RECORD NUMBER

SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

PAGE 10

UPDTE REF	OFFICE	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD	CONTACT TEAM MEMBER-1	MEMBER-2	MEMBER-3	VISITS SCHED	ACTUAL
214		TEPIAC	DR CH HO	317/494-6300	W. LAFAY IN	NW	NP GRODZKA			20-OCT-82	20-OCT-82
215		NASA	H. KREUGER	202/755-3970	HDQTR	EA	M STRAIGHT			16-SEP-82 1-NOV-82	16-SEP-82 1-NOV-82
										16-SEP-82	17-SEP-82
										16-SEP-82	16-SEP-82
										16-SEP-82 15-OCT-82	16-SEP-82 15-OCT-82
										26-AUG-82	26-AUG-82
										26-AUG-82	26-AUG-82
										26-AUG-82	
										26-AUG-82	
										16-SEP-82	16-SEP-82
										-SEP-82	14-SEP-82

REPORT 0 24-MAR-83
SORTED BY ARTEMIS RECORD NUMBER

SPACE STATION NEEDS, ATTRIBUTES & ARCHITECTURAL OPTIONS

PAGE 1

UPDTE REF	OFFICE	AGENCY/ COMPANY	USERNAME	PHONE	LOCATION/ CITY	REG CD	CONTACT TEAM MEMBER-1	MEMBER-2	MEMBER-3	VISITS SCHED	ACTUAL
1	SPACE SYS OUDRE	DOD	CO FORSYTHE	202/697-8157	PENTAGON	EA	M FORSBERG FORSBERG FORSBERG FORSBERG	STECHAN P. SMITH STECHAN P. SMITH	HUNTER P. SMITH HUNTER	13-SEP-82 14-OCT-82 28-OCT-82 17-NOV-82	13-SEP-82 14-OCT-82 28-OCT-82 17-NOV-82
2	NSP (PME 106)	USN	DR. FW DIETRICH	202/692-2102	WASH DC	EA	M FORSBERG FORSBERG	STECHAN P.SMITH	HUNTER	16-NOV-82 16-NOV-82	13-SEP-82 16-NOV-82
3	NSP (PME 106)	USN		202/692-2102	WASH DC	EA	M FORSBERG	STECHAN	HUNTER	13-SEP-82	13-SEP-82
4	NAV OCEANOGRAPHIC	USN	CDR D HONHART	202/254-4562	WASH DC					13-SEP-82 14-OCT-82 27-OCT-82	
5	HQ USAF/INET	USAF	LCOL J B GROSS	202/695-7193	PENTAGON	EA	M FORSBERG FORSBERG FORSBERG	STECHAN P. SMITH	HUNTER	13-SEP-82 15-OCT-82 15-DEC-82	13-SEP-82 15-OCT-82 15-DEC-82

ORIGINAL PAGE IS
OF POOR QUALITY

Lockheed

DEVELOPMENT OF PAYLOAD ACCOMMODATION MISSIONS FROM USER SURVEY

The following list of "Scenarios" are representative of classes of missions NASA uses in their mission models. These tend to be more "function oriented" than mission oriented.

The earliest use date refers to a time when the users we contacted felt a space station with the functional capabilities they required would be beneficial. This date does not drive availability in our growth concept but is simply one input to the capability evolution. The scenarios are described as to functions and impact on operations in other areas of this report.

The scenarios were used in user contacts with the objective of obtaining solid endorsement of some of the scenarios for which requirements could then be defined. This technique, though it did not result in a large number of solidly endorsed missions, proved successful in establishing meaningful dialog with users and led to definition of a substantial number of mission requirements.

SPACE STATION PROGRAMS

DEVELOPMENT OF PAYLOAD ACCOMMODATION MISSIONS FROM USER SURVEY

SOURCE	MISSION SCENARIO	EARLIEST USE
USER SURVEY		
• SCIENCES	LIFE SCIENCE HUMAN RESEARCH LAB	1990
	LIFE SCIENCE NON-HUMAN RESEARCH LAB	1990
	CELESTIAL OBSERVATORY	1990
	SPACE ENVIRONMENT FACILITY	1990
• APPLICATIONS	EARTH OBSERVATION FACILITY	1990
	GLOBAL HABITABILITY OBSERVATION LABORATORY	1990
	METEORLOGICAL FACILITY	1990
• COMMERCIAL	MATERIAL PROCESSING RESEARCH LAB	1990
	MATERIAL PROCESSING FACILITIES	+ 5 YRS
• U.S. NATIONAL SECURITY	SPACE OBSERVATION DEVELOPMENT LABORATORY	1990
	OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB	1990
	ORBITING NATIONAL COMMAND POST - NASA IMPACT	1990
	- OPERATIONAL	1998
	SPACE OBJECTS IDENTIFICATION SYSTEM	1995
• SPACE OPERATIONS	ON ORBIT SATELLITE SERVICING-LEO (ITSS. SBR. GPS)	1993
	LARGE STRUCTURES ASSEMBLY (SBR)	1992
	ASTRONOMY PLATFORM SUPPORT	1990
	SPACE TELESCOPE MAINTENANCE	1990
	PROMPT SATELLITE REPLACEMENT	1993
	SHUTTLE CREW RESCUE VEHICLE	1990
	GEO SATELLITE RESUPPLY	1990

Lockheed

USER ALIGNMENT PLAN
CONCLUSIONS

The approach taken to define space station requirements was to utilize existing data where available, to acquire requirements through personal contacts with potential users. The existing data base provided adequate coverage of requirements in the science area, particularly, physical sciences. A substantial number of personal contacts were made in the life sciences and applications area to expand this data base. Definition of requirements was found to be very limited in the area of commercial applications and therefore a considerable number of personal contacts were initiated and two seminars were held under joint sponsorship of Lockheed and the Arthur D. Little Company. Both the contacts and seminars proved to be beneficial in developing commercial user interest but neither resulted in significant numbers of hard requirements.

Substantial emphasis was placed on U. S. National Security and strong interest has been developed in several areas as a result of our visits.

Tied in closely with the present non-existence of significant requirements was a general lack of knowledge about space. Most people not closely allied to the aerospace industry are not familiar with the environment they would be dealing with and cannot judge the advantages and benefits that are possible.

To develop a broad base for commercial users of space and a space station system, it is imperative for NASA to keep their plans highly visible to potential users as well as to help them become familiar with space characteristics.

SPACE STATION PROGRAMS

USER ALIGNMENT PLAN CONCLUSIONS

- USER ALIGNMENT PLAN SUCCESSFUL
  - RAISED POTENTIAL USER INTEREST
  - CREATED POTENTIAL SPACE BUSINESS OPPORTUNITIES
- USERS NOT READY FOR SPACE STATION
  - MANY POTENTIAL USERS NOT SUFFICIENTLY FAMILIAR WITH SPACE
  - USERS NEED MORE TIME TO DEVELOP THEIR REALISTIC NEEDS
  - MANY USERS DO NOT PLAN 5-7 YEARS DOWNSTREAM
  - POTENTIAL USERS WANT TO KNOW HOW AND WHAT SPACE CAN DO
- WHAT CAN BE DONE?
  - RECOMMEND CONTINUING FOLLOW-UP WITH USER ALIGNMENT PLAN
  - CREATE NASA "SPACE UTILIZATION GROUP" TO HELP POTENTIAL USERS BECOME FAMILIAR WITH SPACE OR PERFORM EXPERIMENTS USING THE STS
  - KEEP SPACE STATION PLANNING VISIBLE TO USERS

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN

1.2 SCIENCE AND APPLICATIONS

— PHYSICAL SCIENCES

— LIFE SCIENCES

1.3 COMMERCIAL

1.4 U.S. NATIONAL SECURITY

1.5 SPACE OPERATIONS

1.6 REQUIREMENTS FROM USER NEEDS

1.7 FOREIGN CONTACTS

Lockheed

SPACE STATION PROGRAMS

PHYSICAL SCIENCES

Lockheed

PHYSICAL SCIENCE USES OF A SPACE STATION (2)

Observatory measurements include most of the research programs that have dominated space physics research during the past two decades. These include measurements of phenomena ranging from as near as the earth's surface to as distant as astrophysical sources.

As an operations center, the space station can enable repair and maintenance of free-flyers as well as instrumentation on the space station. Satellites for planetary exploration can be configured and checked out before being sent on their planetary journey. In addition, extraterrestrial samples can be examined in a laboratory/quarantine facility on the space station. An important use will be construction of large structures too big to be conveniently assembled during a shuttle flight.

The final category of use is an experimental research facility aboard the space station that can take advantage of the low-gravity and high-vacuum that is readily available.

SPACE STATION PROGRAMS

PHYSICAL SCIENCE USES OF A SPACE STATION (2)

- OBSERVATORY MEASUREMENTS
  - EARTH OBSERVATIONS
  - ATMOSPHERIC PHYSICS
  - IONOSPHERIC PHYSICS
  - MAGNETOSPHERIC PHYSICS
  - SOLAR PHYSICS
  - PLANETARY STUDIES
  - ASTROPHYSICS
- OPERATIONS CENTER
  - FREE FLYERS
  - CONSTRUCTION BASE FOR LARGE STRUCTURES
  - PLANETARY EXPLORATION
- EXPERIMENTAL FACILITY
  - ACTIVE SPACE EXPERIMENTS
    - o SPACE PLASMAS
    - o CHEMICAL RELEASES
  - LABORATORY MEASUREMENT/EXPERIMENTS
    - o MICROGRAVITY EXPERIMENTS
    - o VACUUM EXPERIMENTS
    - o MATERIALS SCIENCES LABORATORY
    - o CLOUD PHYSICS LABORATORY
    - o CHEMICAL KINETICS LABORATORY
    - o LOW-GRAVITY PLANETOLOGY
    - o LABORATORY

EXAMPLE OF ADVANCED CONCEPT (1)

GRAVITATIONAL - WAVE INTERFEROMETER

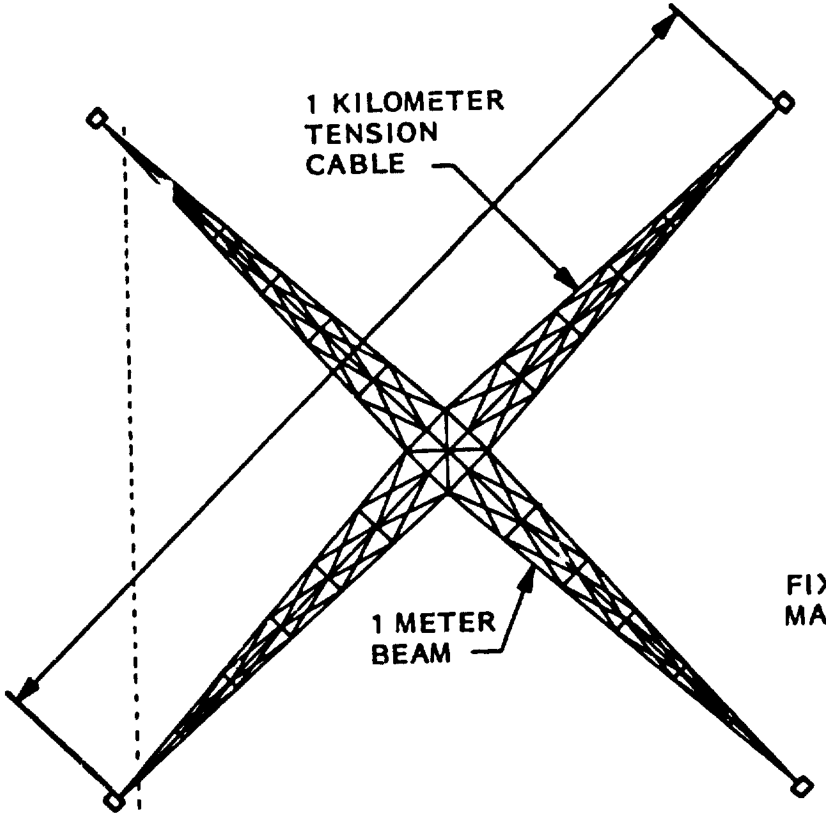
An example of an advanced concept that might require the space station capability is a gravity-wave interferometer. It is a large cross-shaped structure consisting of orthogonal beams, each a kilometer or more in length. One-ton masses are mounted at the four ends of the beams. A laser interferometer system is used to measure the small relative displacement of these masses that would be the signature of the passage of gravity waves. Although it may be feasible to construct and deploy such a system with Space Shuttle alone, the assembly and operation strain the Space Shuttle capability. Thus, this advanced concept may be a system that is made feasible by development of a manned space station.

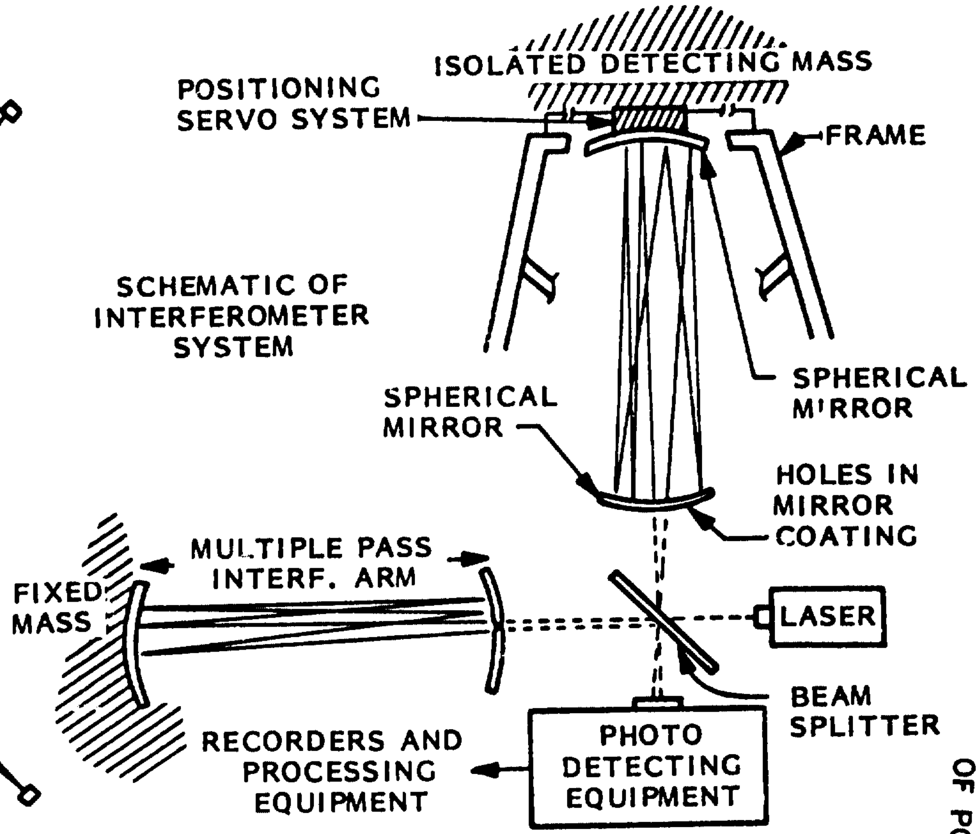
The gravity-wave interferometer is described in more detail in "Gravitational Radiation Searches and Gravitational Wave Astronomy," Astrophysics Program Project Concepts, NASA Headquarters, October, 1980, pp. 21-24.

SPACE STATION PROGRAMS

EXAMPLE OF ADVANCED CONCEPT (1)

GRAVITATIONAL-WAVE INTERFEROMETER





(FROM GRAVITATIONAL RADIATION SEARCHES AND GRAVITATIONAL WAVE ASTRONOMY, ASTROPHYSICS PROGRAM PROJECT CONCEPTS, NASA HEADQUARTERS, OCTOBER, 1980)

Lockheed

EXAMPLE OF ADVANCED CONCEPT (2)

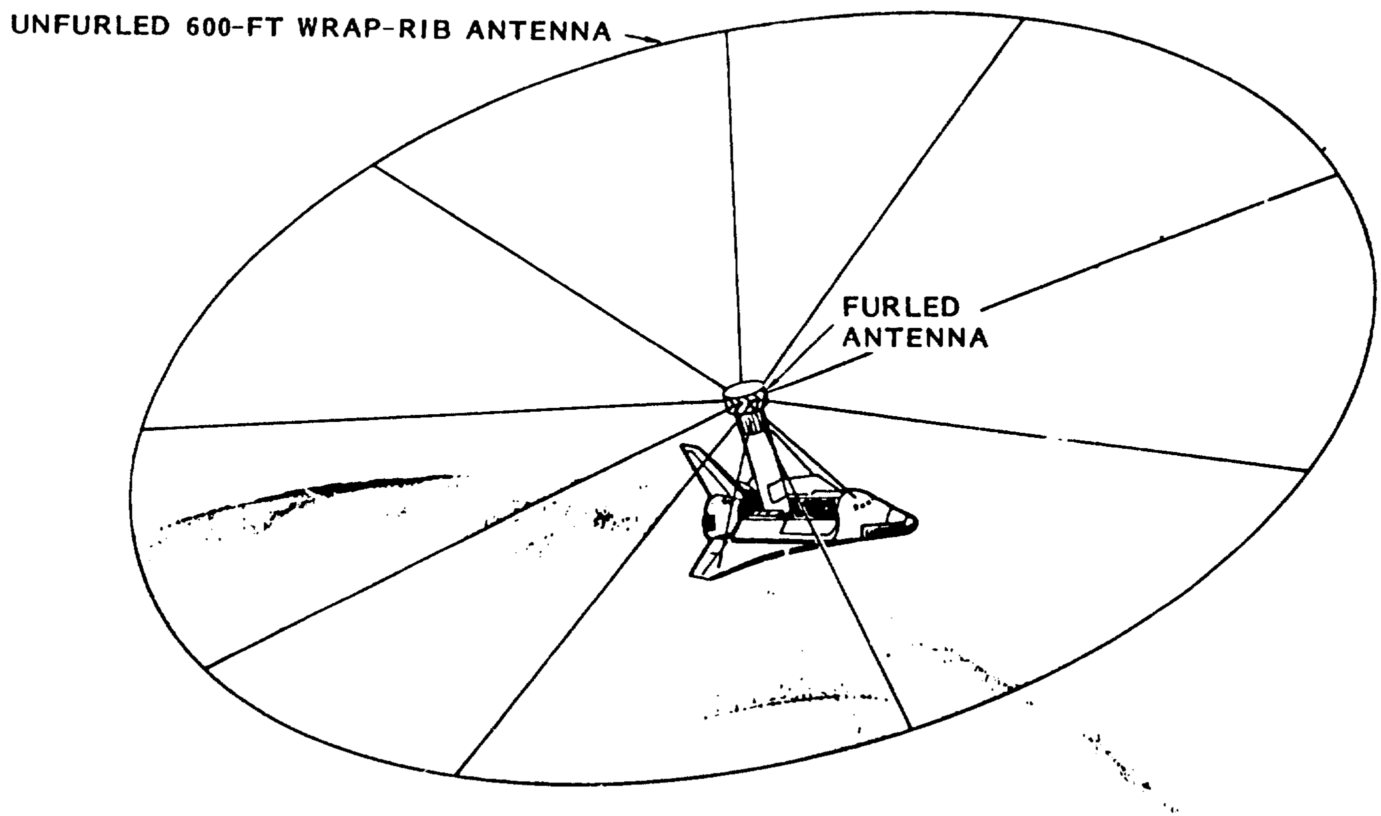
INCOHERENT SCATTER RADAR FACILITY

An incoherent-scatter radar system is another example of a science system that is feasible only on a space station. Incoherent-scatter radars can remotely measure all of the key physical parameters of the ionosphere and upper atmosphere. However, to operate effectively they require a large antenna, high power, and a complex data processing system. For these reasons, an incoherent-scatter radar facility on the Space Shuttle has been judged to be technically feasible, but cumbersome and impractical to implement (M. Baron, R. Tsunoda, J. Petriceks, and H. Kunnes, "Feasibility of an Incoherent-scatter Radar Aboard the Space Shuttle," Stanford Research Institute Report, March 1976; J. Ball, G. Fulks, T. Old, and W. Wortman, "Techniques for Remote Sensing of Ionospheric Electron Density from a Spacecraft," Mission Research Corporation Report, August 1981).

To be effective an incoherent-scatter radar typically requires a peak power-aperture product of about 10^8 watts-m^2. For a peak pulse power of 10kW, an antenna is needed that is approximately 600 ft in diameter. The illustration, taken from the 1976 SRI study, shows the size of this antenna compared to the Space Shuttle. Such a large antenna is probably not practical for an STS sortie mission. However, such an antenna could be deployed as part of a space station; or if large power systems are available, a smaller antenna could be used.

EXAMPLE OF ADVANCED CONCEPT (2)

INCOHERENT-SCATTER RADAR FACILITY



ARTIST'S DRAWING OF 600-FT UNFURLED ANTENNA AND SPACE SHUTTLE (BARON ET AL., 1976)

CONCERNS EXPRESSED BY SCIENTISTS

Despite the many benefits of a space station, concerns have been expressed by scientists. The chart lists the major concerns, as well as ways to alleviate them. In general, remedial action consists of program management by NASA Headquarters to ensure that science user needs are met in space station design and implementation.

These scientist-concerns are discussed in more detail in "Space Science Research in the United States," Office of Technology Assessment Technical Memorandum, September 1982, pp. 12-16.

SPACE STATION PROGRAMS

CONCERNS EXPRESSED BY SCIENTISTS

CONCERN	REMEDY
STATION MAY CONSTRAIN SCIENCE BECAUSE OF ORBITAL LOCATION	RETAIN CAPABILITY FOR ACCESS TO OTHER ORBITS
EXPERIMENT REQUIREMENTS FOR STABILITY, ETC. INCOMPATIBLE WITH A MANNED STATION	INCLUDE SCIENCE REQUIREMENTS IN STATION DESIGN; USE OF SUBSATELLITES
SKEPTICISM REGARDING PROMISED CAPABILITIES BEING ACTUALLY ACHIEVED	PROGRAM MANAGEMENT TO ENSURE ACHIEVEMENT OF CAPABILITIES
IMPACT ON NASA SCIENCE BUDGET	MAINTAIN NASA SCIENCE PROGRAMS
PREEMPTION BY MILITARY	PROGRAM MANAGEMENT, MULTIPLE STATIONS

Lockheed

CONCLUSIONS

Our assessment of user needs for physical sciences and applications resulted in several general conclusions:

1. Significant benefits can result from use of a space station by scientists. The primary benefits result from: The continuous operations over long time periods; the large structures and high power that will be available; and the manned operation, maintenance and repair of complex systems.

2. Most planned science missions are possible with a space station. Mission requirements identified with the ARTS data base were generally compatible with reasonable space station capabilities and do not seriously constrain space station architecture. The major exceptions are missions with unique orbital requirements (e.g., TOPEX).

3. The primary scientific benefit of a space station is that it will enable advanced science missions with requirements that now exceed STS capabilities. These missions have large dimensions, great complexity or high power consumption.

CONCLUSIONS

- A MANNED SPACE STATION CAN BE OF SIGNIFICANT BENEFIT TO THE SCIENTIFIC COMMUNITY
- MANY PLANNED AND APPROVED SCIENCE MISSIONS ARE COMPATIBLE WITH SPACE STATION
- SPACE STATION WILL ALLOW DEVELOPMENT OF SCIENTIFIC SYSTEMS THAT ARE NOW CONSTRAINED BY STS CAPABILITIES

SPACE STATION PROGRAMS

LIFE SCIENCES

Lockheed

REASONS FOR RESEARCH IN SPACE

Over the years the goals of the Space Life Sciences Program have been stated in various NASA documents. Among these are:

- Future Directions for the Life Sciences in NASA
- Life Sciences Division "Ten-Year Plan," July 1982
- Announcement of Opportunity OSS-1-78 Life Sciences Investigations on Space Shuttle/Spacelab Missions
- Space Sciences and Applications Notice, October 1982
- NASA Program Plans
- Annual NASA Budget Request Documents

The chart opposite is an LMSC composite of these goals statements.

SPACE STATION PROGRAMS

REASONS FOR RESEARCH IN SPACE

- TO UNDERSTAND AND MITIGATE THE EFFECTS OF THE SPACE ENVIRONMENT ON HUMANS SO THAT A VARIED SEGMENT OF THE POPULATION CAN PARTICIPATE DIRECTLY IN SPACE FLIGHT
- TO DEVELOP THE FOUNDATION FOR THE EXTENDED PRESENCE OF, AND EXTENDED OPERATION BY, HUMANS IN SPACE
- TO INCREASE MANKIND'S UNDERSTANDING OF THE EFFECTS OF THE UNIQUE SPACE ENVIRONMENT ON BIOLOGICAL PROCESSES
- TO USE THE SPACE ENVIRONMENT TO BETTER UNDERSTAND LIFE PROCESSES ON EARTH
- TO UNDERSTAND THE ORIGIN, EVOLUTION, NATURE, AND DISTRIBUTION OF COMPLEX LIFE IN THE UNIVERSE, AND TO UNDERSTAND ITS INTERACTION WITH THE ENVIRONMENT

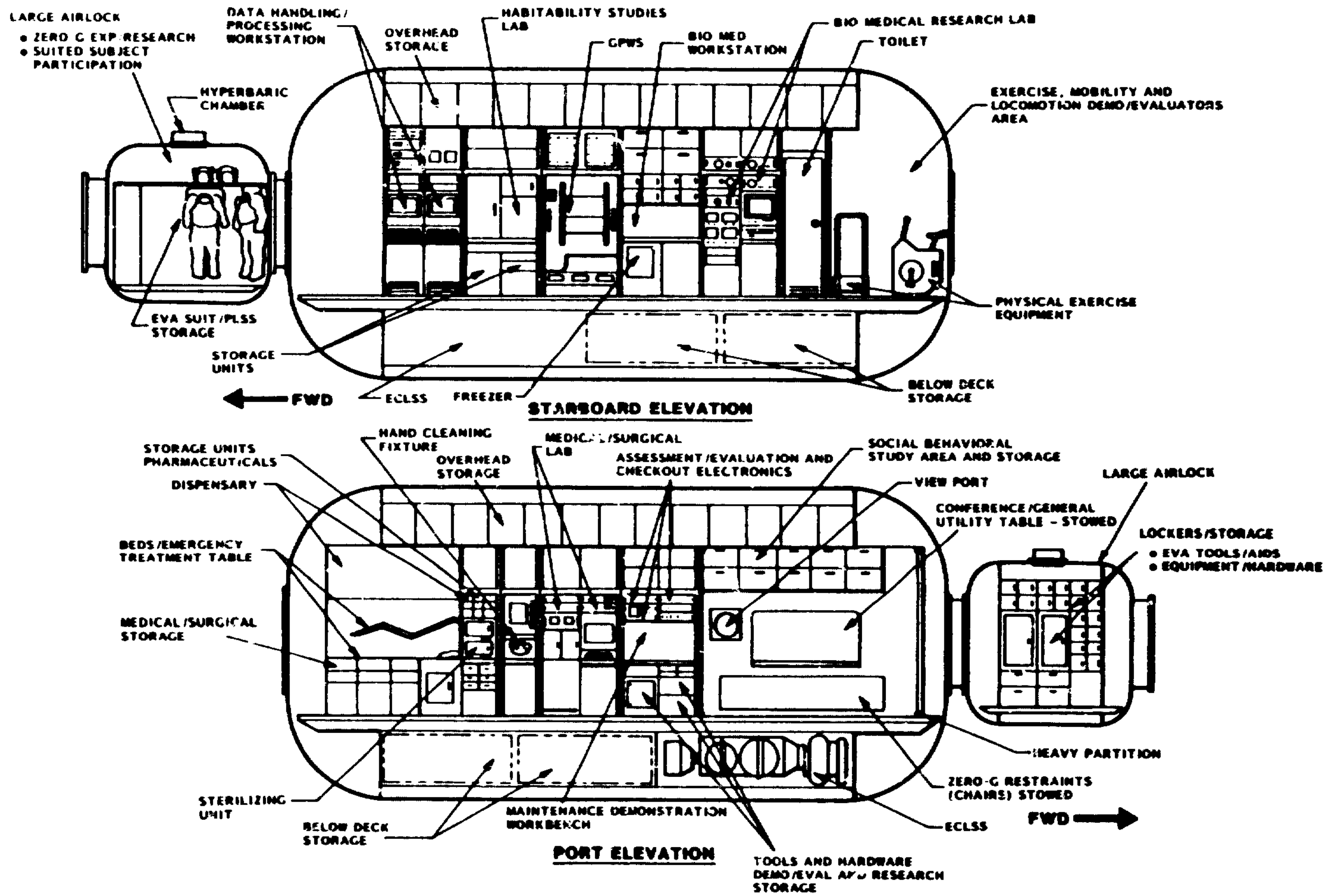
Lockheed

STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)

Additional details of this facility are shown in these port and starboard elevations.

SPACE STATION PROGRAMS

STRAWMAN HUMAN RESEARCH AND HEALTH MAINTENANCE FACILITY (1)



ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

ARCHITECTURAL CONSIDERATIONS

The impact of life sciences research on space station architectural considerations is presented for both near-term and long-term situations. Studies to date have concluded that the human research laboratory will evolve from the health maintenance facility, which is justified easily on the basis of the cost of a single rescue mission.

A nonhuman laboratory is needed to allow invasive and prolonged experiments that cannot be conducted on humans. This facility will be separate from the human research laboratory but attached to the station and will contain a shirt-sleeve environment. The large investment in Spacelab equipment cannot be ignored, therefore, space station hardware will be similar to Spacelab hardware where possible.

Plant experiments may be conducted on free flyers but animal experiments will probably not be. There is an advantage to free flyers for plant studies because plant physiologists want low gravity, e.g., 10^{-4} g or less and no disturbances such as crew movements or docking. However, automating an animal experiment to be flown on a free flyer would be extremely costly.

In the long term there are two significant areas where life sciences considerations may have a major impact on the architecture of a space station. These are in the areas of radiation shielding and artificial gravity. A space station at geosynchronous orbit or a space settlement requires considerable shielding to reduce radiation to near terrestrial levels.

The issue of artificial gravity has not been completely laid to rest. The end point of some physiological phenomena such as calcium loss has not been determined and future research may establish that artificial gravity is required. This could have a significant impact on the configuration of a space station.

ARCHITECTURAL CONSIDERATIONS

NEAR TERM

- HUMAN RESEARCH LABORATORY WILL EVOLVE FROM HEALTH MAINTENANCE FACILITY
- HEALTH MAINTENANCE FACILITY EASILY JUSTIFIED ON BASIS OF COST OF RESCUE MISSION
- NONHUMAN LABORATORY NEEDED TO ALLOW INVASIVE OR PROLONGED RESEARCH REQUIRED FOR FURTHER UNDERSTANDING OF BIOLOGICAL EFFECTS OF SPACE
- NONHUMAN LABORATORY WILL BE SEPARATE FROM HABITATION MODULE, BUT ATTACHED TO SPACE STATION
- LARGE INVESTMENT IN SPACELAB EQUIPMENT CANNOT BE IGNORED
- PLANT EXPERIMENTS MAY BE CONDUCTED ON FREE FLYERS, BUT ANIMAL EXPERIMENTS WILL NOT

FAR TERM

- LIFE SCIENCES CONSIDERATIONS COULD BE MAJOR DRIVER ON LONG DURATION MISSIONS
    - RADIATION SHIELDING
    - ARTIFICIAL GRAVITY

ARTIFICIAL GRAVITY CONSIDERATIONS

Because of health and performance problems associated with weightlessness, some level of artificial gravity may be desirable and may be required in long-term space stations. Known health problems include bone demineralization, which has no known end point or zero-gravity countermeasure. A lesser problem is space sickness to which adaptation occurs normally within a few days and always, so far, within one week. Cardiovascular deconditioning, hormone and electrolyte imbalances, and muscle loss all are persistent manifestations of zero gravity. Performance degradations also are known to occur. Locomotion is difficult, and balance and material handling are abnormal.

If rotation is used to provide a level of artificial gravity, its physical effects must be considered in the design. These include Coriolis effects that change the g-level with perpendicular linear movements and cross-coupled angular accelerations associated with body and head movements. Gravity gradient could be important in very short radius systems. Motion sickness could be evoked by head movements or transitions from weightless sections of the craft to artificial gravity areas.

Tether concepts should be explored since these produce a linear artifical gravity field. The tether length to produce gravity levels above 0.05g may be impractical from operational considerations, however.

SPACE STATION PROGRAMS

ARTIFICIAL GRAVITY CONSIDERATIONS

- HEALTH PROBLEMS OF NO GRAVITY
  - BONE DEMINERALIZATION - NO KNOWN END POINT
  - SPACE SICKNESS - ADAPTATION WITHIN ONE WEEK
  - CARDIOVASCULAR DECONDITIONING - PERSISTENT
  - HORMONE AND ELECTROLYTE IMBALANCES - PERSISTENT
  - MUSCULAR ATROPHY - PERSISTENT

- HUMAN PERFORMANCE
  - SELF LOCOMOTION
  - MATERIAL HANDLING
  - TRANSITION FROM ARTIFICIAL GRAVITY TO WEIGHTLESSNESS
  - POSTURAL BALANCE

- PHYSICAL EFFECTS OF ROTATION
  - CORIOLIS - CROSS COUPLED ANGULAR ACCELERATIONS
    - MOTION SICKNESS
  - GRAVITY GRADIENT

  TETHER CONCEPT AVOIDS THESE PROBLEMS

RECOMMENDATIONS REGARDING ARTIFICIAL GRAVITY

The artificial gravity requirement is very ill-defined at this time. Most investigators feel it is going to be needed, but rotation rates and g-levels are subject to widely differing opinions.

A research program is needed, and must be conducted in the weightless space environment to produce meaningful results. The major tool for the research is a variable gravity centrifuge. This has been planned by NASA for the dedicated Life Sciences Spacelabs, although no budget authority has been provided to proceed with flight hardware. Information from Spacelab is needed to plan further studies in space station facilities, ultimately leading to a design decision on artificial gravity.

SPACE STATION PROGRAMS

RECOMMENDATIONS REGARDING ARTIFICIAL GRAVITY

- RESEARCH IS REQUIRED <u>IN SPACE</u> ON
  - ROTATION RATES - HUMAN ADAPTATION, LONG-DURATION HABITABILITY, TRANSITION EFFECTS BETWEEN ROTATING AND NONROTATING AREAS
  - G-LEVEL VARIATIONS - ASSOCIATED WITH RADIAL MOVEMENTS - CONTINUOUS AND STEPPED
  - LOW-G TOLERANCE - LONG-TERM PHYSIOLOGICAL EFFECTS OF ZERO AND FRACTIONAL G-LEVELS
- A LARGE-RADIUS RESEARCH CENTRIFUGE SHOULD BE GIVEN URGENT PRIORITY FOR THE SECOND DEDICATED LIFE SCIENCES SPACELAB (SL-10) AND SUBSEQUENT FLIGHTS.
- THE SPACE STATION SHOULD INCLUDE CAPABILITY FOR RESEARCH IN ROTATIONAL HYPOGRAVITY, BOTH WITH HUMAN AND NONHUMAN SUBJECTS.
- SYSTEM STUDY AND EXPERIMENTS ARE REQUIRED ON LINEAR ARTIFICAL GRAVITY FIELD (TETHER SYSTEM).

Lockheed

CONCLUSIONS

The environment of space provides a unique dimension for the study of human, animal, and plant physiology. This will surely result in additional knowledge leading to health and other benefits. A space station life sciences research facility is a mandatory step to obtain the answers required for future activities such as interplanetary exploration. One of the more significant research areas to be explored in this respect is defining man's capability in space. Life sciences clearly is one of the justifications for manned activities in space.

CONCLUSIONS

- SPACE PROVIDES A NEW DIMENSION FOR LIFE SCIENCES RESEARCH
- SPACE STATION IS A MANDATORY STEP TO OBTAIN LIFE SCIENCES ANSWERS FOR FUTURE
- LIFE SCIENCES PROVIDES SIGNIFICANT JUSTIFICATION FOR MANNED ACTIVITIES IN SPACE

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN
1.2 SCIENCE AND APPLICATIONS
— PHYSICAL SCIENCES
— LIFE SCIENCES
1.3 COMMERCIAL
1.4 U.S. NATIONAL SECURITY
1.5 SPACE OPERATIONS
1.6 REQUIREMENTS FROM USER NEEDS
1.7 FOREIGN CONTACTS

Lockheed

BENEFITS OF SPACE COMMERCIALIZATION

With the tremendous growth of the satellite communication industry still going strong, proof of space business opportunity is there. Spin-offs from these space ventures require no proof. Starting with early space exploration a large number of spin-offs have become profitable ventures here on earth.

Space is probably the last remaining frontier and it will certainly yield its secrets as more time is spent in that environment. Commercial opportunities will show themselves in space as the obvious ones already have.

SPACE STATION PROGRAMS

BENEFITS OF SPACE COMMERCIALIZATION

- COMMUNICATION SATELLITES ALREADY CREATED A NEW INDUSTRY AND SPIN-OFFS
- THE LAST REMAINING FRONTIER-WILL CREATE BUSINESS OPPORTUNITIES
  - -- REMOTE SENSING (GROWTH)
  - -- MATERIALS PROCESSING (START)
  - -- UTILITY SERVICES (LONG TERM)

Lockheed

COMMERCIALIZATION OF FUTURE ACTIVITIES IN SPACE

A number of potential activities for commercial activities in space are presented. The timing for commercialization for most is probable in the coming decade, some of the presently less obvious possibilities could come at a later date. Although the list contains areas that seem highly improbable at present, we have still left these without giving them a lot of attention. One of these areas is medical services, which on present impulse should be withdrawn however, early withdrawal may not be prudent. Drugs and alloys may offer the best possibilities and should be vigorously pursued. Sensors are of course already in wide use but there use and sophistication will improve many fold during the next decade with long term space research.

SPACE STATION PROGRAMS

COMMERCIALIZATION OF FUTURE ACTIVITIES IN SPACE

TIMING FOR COMMERCIALIZATION	APPLICATION	INDUSTRY SECTOR	PARTICIPANTS
1985 - '95	DRUGS	PHARMACEUTICALS	RESEARCH EQUIP. VENDORS DRUG FIRMS PROCESS EQUIP. VENDORS
1985 - '95	ALLOYS	METALS	RESEARCH EQUIP. VENDORS
1985 - '95	SEMICONDUCTORS	ELECTRONICS	ELECTRONIC FIRMS EQUIPMENT VENDORS
1985 - '95	SENSORS	AEROSPACE	AEROSPACE FIRMS
1985 - '95	TELECOMM. PLATFORMS	COMMUNICATIONS	ELECTRONICS AEROSPACE EQUIPMENT VENDORS
1990 - 2000	MEDICAL SERVICES	HEALTH CARE	DOCTORS' ORGANIZATIONS HOSPITAL ORGANIZATIONS
1990 - 2000	FACILITY CONSTRUCTION	CONSTRUCTION	A&E FIRMS EQUIPMENT VENDORS
1985 - 2000	UTILITY SERVICES	MANUFACTURING	AEROSPACE EQUIPMENT VENDORS

Lockheed

MATERIAL PROCESSING IN SPACE (1)

Very little materials processing has been done in space in the past. Data in this area has to come from experiments planned for flight in the coming years. Specific industries should be researched and experiments with their specialized requirements in mind should be conducted. The positive results of these experiments will draw the commercial interest that has been lacking so far.

Industrial capital investors want to know what their return will be and when, against what probability of success. This means that what we want to do in space has to be well defined when presenting it.

SPACE STATION PROGRAMS

MATERIAL PROCESSING IN SPACE (1)

AMERICAN ACTIVITY

- NASA COMMITMENT FOR MPS EFFORT HAS NOT INCREASED SIGNIFICANTLY (ABOUT $20M)
- EXPERIMENTERS MAINLY DRAWN FROM NASA, UNIVERSITIES, RESEARCH INSTITUTES, AND AEROSPACE COMPANIES
- TRUE COMMERICAL PARTICIPATION NOTABLE BY ITS ABSENCE (SAME IN OTHER COUNTRIES)

  NOTE: EXCEPTION - MDAC/JOHNSON & JOHNSON
- NASA STUDY CONTRACTS DESIGNED TO INVOLVE AND DRAW IN THE COMMERCIAL INTEREST
- STATION ARCHITECTURE AND COSTING ACTIVITIES IN PROGRESS

Lockheed

CHALLENGES TO COMMERCIAL ACTIVITIES

With the increasing attention given to space station and space exploitation, also on the international scene, it becomes more important to focus on the legal aspects for this new and lost frontier. Maybe a "Law of Space" similar to the "Law of the Seas" should be investigated. The third nations that are presently not in a military nor in an economic position to involve themselves with space, are stirring up a move of participation and evan national ownership of space.

Some other issues will have to deal with in the very near future, they are the federal regulations that will control the total space operation.

On a more direct basis, the NASA interface with the commercial world has to be looked at. It may be too early to suggest that there be no direct interface but rather an aerospace company buffer between NASA and commercial enterprises.

SPACE STATION PROGRAMS

CHALLENGES TO COMMERCIAL ACTIVITIES

LEGAL AND REGULATORY ISSUES

- OWNERSHIP OF EXTRATERRESTRIAL RESOURCES
- PROTECTION OF PROPRIETARY RIGHTS
- ANTITRUST CONFLICTS

INTERFACES WITH FEDERAL GOVERNMENT

- REGULATIONS
- INTERFERENCE WITH OPERATIONS
- ACCOUNTABILITY
- LIABILITY
- COMMUNICATIONS

POTENTIAL CONFLICT WITH DoD ACTIVITIES

CONCLUSION ON COMMERCIAL CONTACTS

Contacts made for the seminar yielded a lower percentage of attendance than a direct telephone call or letter. The direct telephone and letter approach does cost more time for the person making the contacts, but the yield is high.

In general a lot of interest for space work was instilled in the people contacted. Surprisingly the total knowledge available about space in general and NASA in specific in the commercial areas is rather minimal. More information needs to be relayed to a broader base of industries.

Most people contacted were willing to look into the possibilities for them in space. The problem was that many did not know how and where to start, which is a sign of not knowing what space can do for them.

SPACE STATION PROGRAMS

CONCLUSION ON COMMERCIAL CONTACTS

- APPRECIABLE INTEREST WAS EXHIBITED BY MAJORITY OF CONTACTS
- AGREEMENT THAT THE USA MUST BE FIRST IN HIGH TECHNOLOGY TO WITHSTAND FOREIGN COMPETITION
- REALIZATION OF THE NEED TO EXPLORE THE PROFITABILITY OF SPACE EXPLOITATION
- NUMEROUS QUESTIONS ON HOW SPACE WOULD IMPROVE PRESENT PROCESSES
- REQUESTS TO SHOW IMPROVEMENT POSSIBLE - "SHOW ME A SAMPLE"
- SMALL NUMBER HAVE MONEY AVAILABLE HOWEVER. THEY WANT A 5-6 YEAR RETURN
- MOST WANT TO BE KEPT INFORMED JUST IN CASE SOMETHING MAY TURN UP
- ELECTRONICS AND METAL PROCESSING ARE PROBABLY ABOUT 5 YEARS OFF
- PHARMACEUTICALS LOOK PROMISING FOR NEXT 3 YEARS MAINLY BECAUSE OF ELECTROPHORESIS
- COMMUNICATIONS WILL CONTINUE TO GROW. HOW MUCH SPACE STATION WILL HELP IS STILL A QUESTION

Lockheed

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN

1.2 SCIENCE AND APPLICATIONS
- — PHYSICAL SCIENCES
- — LIFE SCIENCES

1.3 COMMERCIAL

1.4 U.S. NATIONAL SECURITY

1.5 SPACE OPERATIONS

1.6 REQUIREMENTS FROM USER NEEDS

1.7 FOREIGN CONTACTS

Lockheed

MILITARY BENEFITS OF A SPACE STATION

There is general agreement that there are three primary areas of potential military benefits from a manned space station. Research and development missions offer the most immediate promise for beneficial return. Programs that require evaluation on orbit will benefit by the extended mission duration compared with the time available from the space shuttle. An example of such a program is Talon Gold, which can perform its mission in the 5-day shuttle flight but could realize potentially substantial additional information with a 15 day or more flight. A second program that clearly benefits from extended duration on orbit is the Navy oceanographic sensor development activity that will be discussed further in the following pages.

A second category for which a space station might benefit military uses of space is in the logistics and resupply of satellite systems. The refueling, modification, maintenance and repair, and large structures assembly are all tasks that will play key roles in satellite servicing activities. For the most part satellites must be specifically designed to take advantage of servicing capabilities, and most existing systems will not benefit from satellite servicing operations. By the time a space station is operational, however, a new generation of satellites will be in orbit and if these are properly designed, space-based satellites servicing can play an important role. It is important to evaluate space-shuttle-based servicing compared to space-station-based servicing, however, because of the constraints imposed by orbit mechanics that limit the frequency of revisit opportunities from a space station to specific satellites.

The direct involvement of a space station in operational missions is perhaps the most important, and least well defined, area for potential military benefits of a manned system. Although research and development missions and logistics and resupply missions will make use of a station if it is there, it is unlikely that requirements in these categories will provide a compelling reason for proceeding with a space station. Operational missions, on the other hand, can form a major incentive to proceed with space station development and for that reason these missions are of prime interest. It is possible that the command and control mission for the space station may provide a compelling reason to proceed with the initial phases of space station evolution.

MILITARY BENEFITS OF SPACE STATION

- RESEARCH AND DEVELOPMENT MISSIONS
  - IMPROVED PROGRAM PERFORMANCE WITH LONGER TIME IN ORBIT.
    E.G., TALON GOLD
  - SENSOR DEVELOPMENT - MANNED INTERACTION DURING TEST.
    E.G., NAVY OCEANOGRAPHIC SYSTEMS

- LOGISTICS AND RESUPPLY
  - E.G., REFUEL ATTITUDE CONTROL. MANEUVER PROPELLANTS. SATELLITE SERVICING (MAINTENANCE AND REPAIR) ON ORBIT. AND LARGE STRUCTURES ASSEMBLY
  - NEED TO EVALUATE SHUTTLE VS. SPACE STATION

- OPERATIONS
  - COMMAND AND CONTROL.
    E.G., EXTENSION OF NATIONAL MILITARY COMMAND SYSTEM
  - SPACE OBSERVATION

SPACE STATION PROGRAMS

U. S. NATIONAL SECURITY

R&D MISSION SCENARIO

OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY

Lockheed

OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIO

Personnel in the U.S. Navy have expressed considerable interest in expanding existing capabilities for surveillance of the oceanographic characteristics of the high seas. They have found that manned observation from the Apollo, Skylab, and most recently Shuttle orbiter have provided data that cannot be obtained from data recorded by remote sensors. The strong feeling is that once we understand the phenomena being observed by the unaided eye of the astronaut, we will be able to develop remote sensors or interpret the signal of existing sensors, and subsequently implement an unmanned system to detect the features of interest. Thus, the objective here is to use a combination of manned observation and remote sensor data simultaneously to establish the correlation necessary to select operational remote-sensing designs. It is presumed that manned involvement from space is required during the development phase only and that the operational phase will function in a conventional manner such as LandSat or SeaSat.

This mission is especially well suited to a space station because it combines two key elements: the requirement for manned observation and involvement in space, and the need for an extended period on orbit. Oceanographic phenomena of interest changes slowly with time and it is necessary to make measurements over a period of months in order to obtain the desired data on characteristics such as thermoclines or the presence or absence of long-wave-length deep ocean waves. The change in the characteristics of these features with time is also of particular interest. Though Shuttle-based observations have been helpful in demonstrating the need for visual observation by man in space, the flight duration is too short to provide the scope of data required for this development activity.

SPACE STATION PROGRAMS

OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIO

MISSION CATEGORY: U.S. NATIONAL SECURITY

SYSTEM/PROGRAM: OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LABORATORY

OBJECTIVE:

- TO DEVELOP MULTISENSOR SYSTEMS AND EXPAND EXISTING CAPABILITIES
- TO PROVIDE MEANS FOR EXTENDED REALTIME OBSERVATION OF DYNAMIC OCEAN PHENOMENA AND CONTROL OF SENSOR POINTING AND DUTY CYCLES
- TO CORRELATE VISUAL OBSERVATIONS IN SPACE AND DATA FROM VARIOUS SENSORS
- TO PROVIDE MEANS TO REDUCE DEVELOPMENT COSTS AND TO MINIMIZE DEVELOPMENT SPANS BY MAKING USE OF MANNED CAPABILITIES
- TO PROVIDE DATA TO EVALUATE ROLE OF MAN IN AN OPERATIONAL ENVIRONMENT

SYSTEM DESCRIPTION:

LIFETIME:	3 TO 6 MONTHS PER EXPERIMENTAL SEQUENCE
	10 YEAR USEFUL OPERATION
LAUNCH VEHICLE:	SHUTTLE
TRANSFER VEHICLE:	NONE REQUIRED FOR PAYLOADS HARD-DOCKED ON SPACE STATION
	TMS REQUUIRED FOR CLUSTER FREE FLYER
OPERATIONAL LOCATIONS:	300 - 700 KM AT 65 DEGREES PREFERRED
	300 KM AT 28.5 DEGREES USEFUL

Lockheed

OCEANOGRAPHIC OBSERVATION DEVELOPMENT LAB (CONT)

The essence of this development lab scenario is that equipment will be repositioned, modified, or changed out while on orbit in order to assess the effect of the equipment location, pointing angle or configuration on remote sensor data. It is vital to provide the correlation with manned observation from space made from the identical position and at the same time. Thus the instruments must be located onboard the spacecraft with the astronaut making the observations. Another aspect of this development lab concept is that experimental (brassboard) sensors can be evaluated and this offers the potential of greatly reducing the time for taking laboratory concepts through the development cycle to operational configurations.

The size of the crew necessary to do the development work depends upon the type and complexity of equipment change and modifications anticipated on orbit.

SPACE STATION PROGRAMS

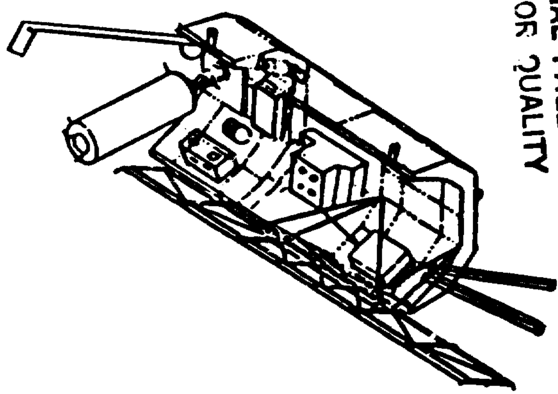
OCEANOGRAPHIC OBSERVATORY DEVELOPMENT LAB MISSION SCENARIO (CONT)

SYSTEM DESCRIPTION: (CONT)

TOTAL MASS AT OPERATIONAL LOCATIONS:	TBD (BUT LESS THAN 14,000 KG)
AVERAGE OPERATIONAL POWER:	TBD (BUT LESS THAN 5 KW)
DESIRED INITIAL OPERATIONAL DATE:	1988 (SHUTTLE-BASED EXPERIMENTS)
	1990 (SPACE-STATION-BASED EXPERIMENTS)

GENERAL NEEDS:

- EQUIPMENT TO BE MOUNTED ON EXISTING PALLET (E.G., ESS OR SPACELAB PALLET)
- LABORATORY IS TO BE CAPABLE OF SUPPORTING EXPERIMENTAL (BRASSBOARD) HARDWARE AND SENSORS
- PHYSICAL CHARACTERISTICS:
  30FT X 14 FT DIAMETER
  UP TO 40FT ANTENNA (SORTIE) EXPANDABLE OR UNFOLDABLE
  UP TO 300FT ANTENNA (FREE FLYER)
- OPERATIONAL CREW:
  2 EXPERIMENTERS MINIMUM (NO EQUIPMENT MODS)
  10 MAN CREW (TECHNICIANS)
- DATA:
  ONBOARD DATA PROCESSING, 10^3 MBPS



ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

IMPACT ON NASA STATION FROM OCEANOGRAPHIC AND SPACE OBSERVATION DEVELOPMENT LABS

These two national-security mission scenarios are typical of the missions thath support the use of the NASA station as a research and development facility. The payloads will be designed to be compatible with space-shuttle pallets, and thus establish the requirement for the space station to directly support attached payloads of this configuration. A need for ability to change equipment configuration and orientation imposes the need for easy shirt-sleeve access to the equipment module or to key elements of the equipment module from the main space station laboratory area. These typical missions also indicate that a crew of two to ten technicians must be accommodated during the course of the experiment activities. The technicians will not necessarily be part of the basic space station crew.

SPACE STATION PROGRAMS

IMPACT ON NASA STATION

FROM OCEANOGRAPHIC DEVELOPMENT LAB AND SPACE OBSERVATION DEVELOPMENT LAB

- TYPICAL MISSIONS SUPPORT THE ROLE OF NASA STATION AS A NATIONAL SPACE R&D FACILITY

- THEY ESTABLISH REQUIREMENT TO SUPPORT:
  - SHUTTLE-COMPATIBLE EQUIPMENT PALLET
  - SHIRT-SLEEVE ENVIRONMENT FOR EQUIPMENT MODULE
  - TECHNICAL CREW OF 2 TO 10 EXPERMENTERS/TECHNICIANS

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN
1.2 SCIENCE AND APPLICATIONS
 — PHYSICAL SCIENCES
 — LIFE SCIENCES
1.3 COMMERCIAL
1.4 U.S. NATIONAL SECURITY
1.5 SPACE OPERATIONS
1.6 REQUIREMENTS FROM USER NEEDS
1.7 FOREIGN CONTACTS

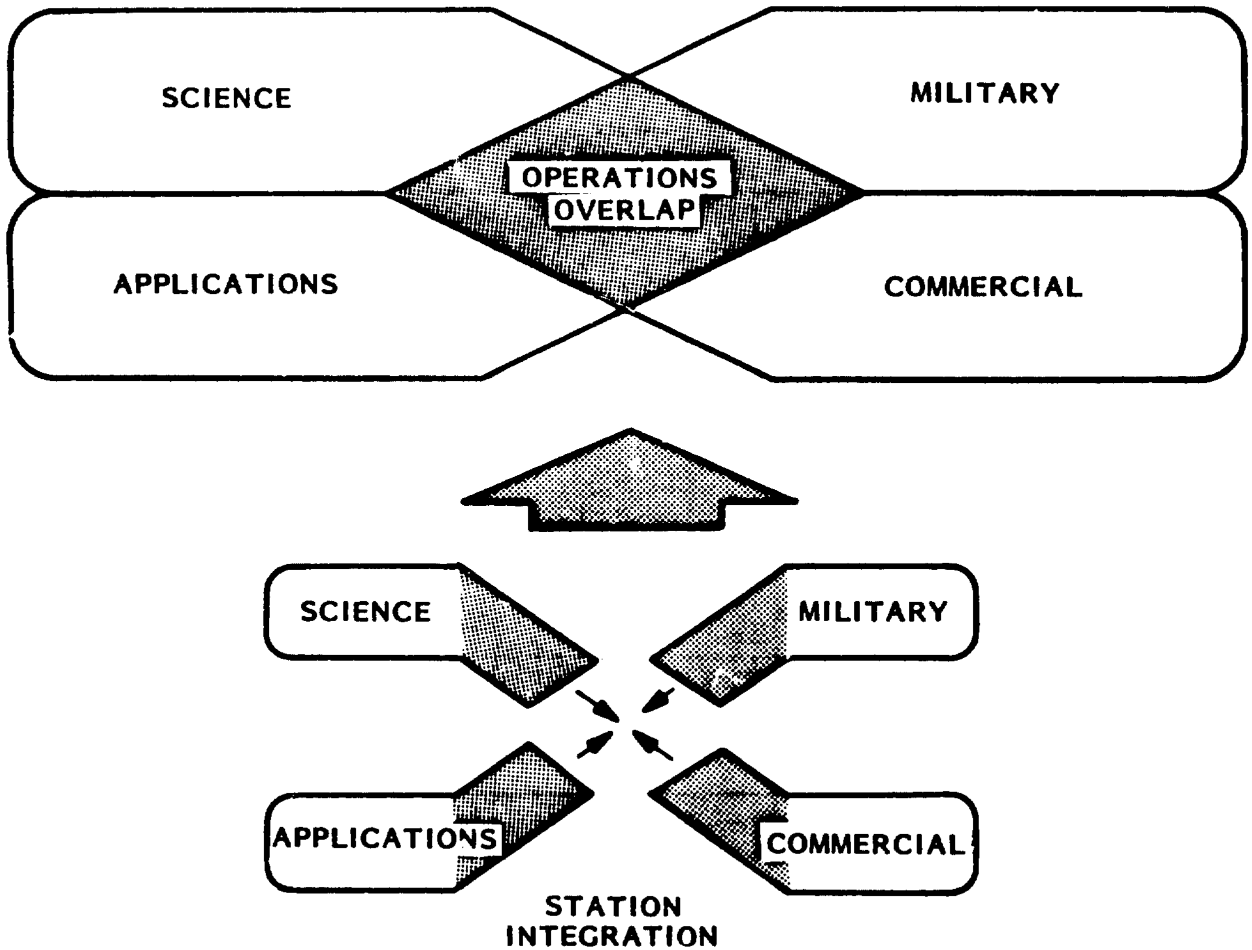
Lockheed

OPERATIONS OVERLAP

Space-based activities will support users from science, applications, national security, and commercial areas. The distinction between various categories of space operations is based on the type of activity to be performed, which will reflect the assimilated needs and define the operations overlap of the specific end users. An even stronger distinction is imposed by the location of space operations (e.g., on-board, near the space station, or far distant). Since much of the activity will not be on-board, space operations are discussed in terms of orbit mechanics constraints rather than user category or activity.

It is recognized that flight crew time-line constraints are important along with power requirements and other considerations. However, until missions are more clearly defined, remote operations will impose maximum impact on the station architecture and thus are emphasized at this time.

OPERATIONS OVERLAP



SPACE STATION PROGRAMS

CONSTRAINTS IMPOSED BY ORBIT MECHANICS

Lockheed

PRECEDING PAGE BLANK NOT FILMED

PAGE 74 INTENTIONALLY BLANK

SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

The mission scenarios were selected to be representative of the five categories of space operations. The astronomy platform is included in two categories to define the differences (if any) between a tethered platform and free flyers, from the mission user point of view.

Each mission was discussed with users for each area. Generally, space-based operations is viewed as one of the primary purposes of the space station and users philosophically endorse these mission descriptions on that basis. Of the mission scenarios, however, only Space Telescope is far enough along to provide solid endorsement. The ITSS space-based radar satellite study was performed in sufficient depth to provide the basis for good cost projections comparing Shuttle-based servicing with station-based servicing (station-based servicing has significant cost advantages, as shown later). However, results of the LMSC ITSS study show that satellite servicing is not cost effective since the study groundrules were that the vehicle had to carry onboard propellant for return to the Shuttle for servicing. This is a reasonable requirement for programs planned for operation in 1985 to 1990; however, it must be reexamined for systems to be operational in the mid-1990s.

Space-station-based support assumes that the station is in the proper inclination. Thus, one station at 28.5-deg. could support six of the seven missions (the astronomy platform is counted only once); a station at 60-deg. is required to support space-based radar maintenance.

SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

ON-BOARD OPERATIONS

1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
   - o LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
   - o ASTRONOMY PLATFORM SUPPORT (TETHERED)

REMOTE OPERATIONS

2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
   - o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)

3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
   - o SPACE TELESCOPE MAINTENANCE
   - o SPACE BASED RADAR (ITSS) MAINTENANCE

4- UNIVERSAL SUPPORT OF LEO SATELLITES
   - o PROMPT SATELLITE REPLACEMENT
   - o SHUTTLE CREW RESCUE VEHICLE

5- UNIVERSAL SUPPORT OF GEO SATELLITES
   - o GEO SATELLITE RESUPPLY

SPACE STATION PROGRAMS

CATEGORY 1

HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYERS, TETHERED SATELLITES

Lockheed

CAPTIVE FREE-FLYER

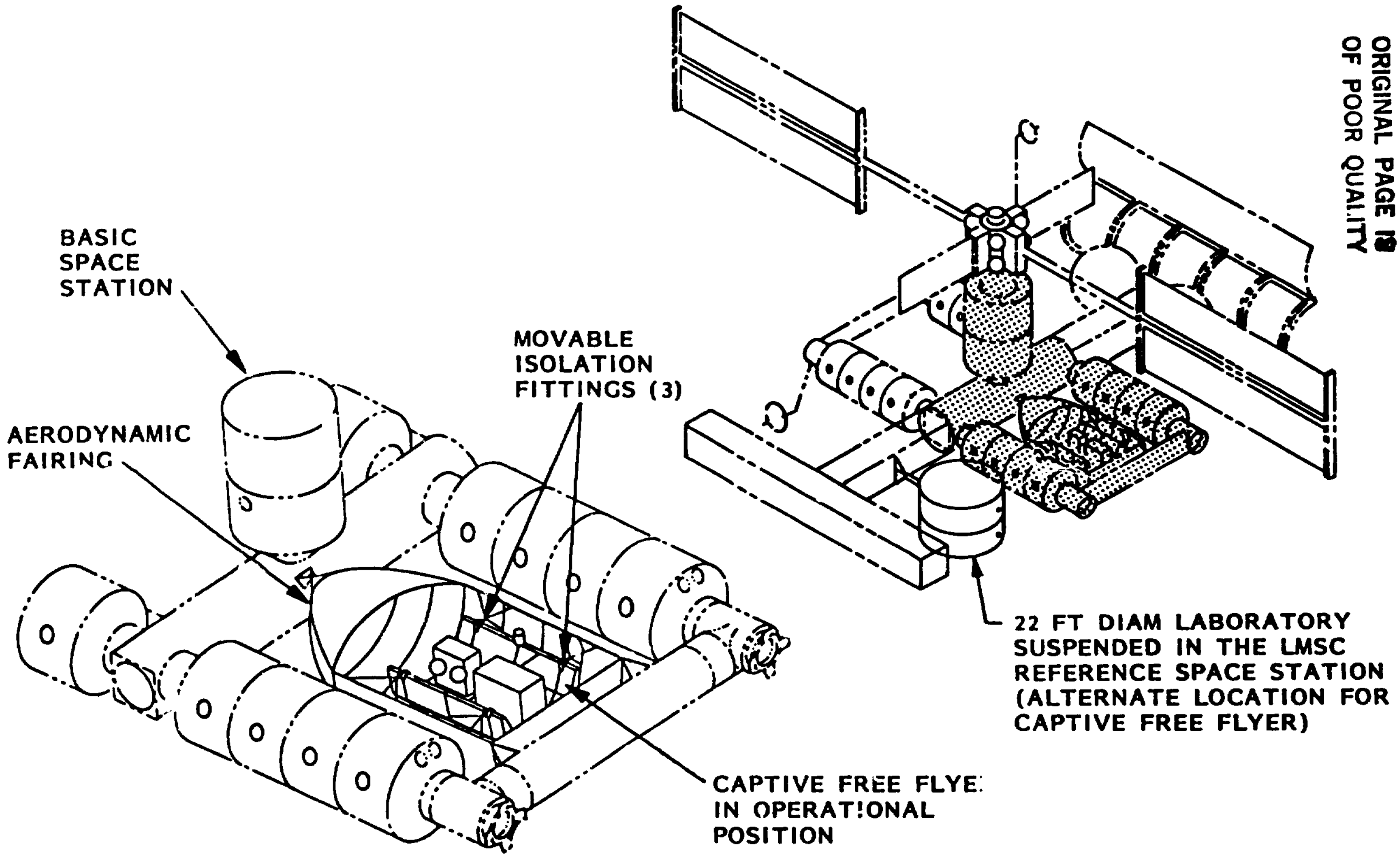
While the impact of hard-docked payloads on the orbit mechanics of the space station presents no conceptual restraints, a hard-docked payload is subjected to the transient dynamic loads transferred through the station structure. This can have an adverse effect by disturbing the desired very low-g environment which some users (such as materials processing producers) assume they must have for extended periods of time. One way to obtain very low-g is to mount the experiment on a free-flying satellite which orbits the station (see category 2). This has the disadvantage that manned interaction with an experiment (or production process) on a frequent basis is difficult, or at the least inconvenient.

An alternative is to mount the payload on a support pallet contained inside a support structure envelope on the space station. While work is performed on the payload, it is hard-mounted to the station. During payload operation when low-g is desired, all supports are removed. An aerodynamic fairing can be used to create an even higher vacuum in its wake and to minimize the already very small drag forces. The effect of the surrounding space station structure on the vacuum level, as well as general contaminataion effects, will have to be examined for each specific configuration. Hardware based on such concepts have flown on many satellites, usually as a solid sphere inside a spherical container, and were used to provide signals for an inertial guidance and control system. The extension of this concept to a free-floating 20,000-lb payload with furnaces and radiators, as well as requirements for power and communication, may be nontrivial, but it is an appealing approach with potentially substantial benefits.

This approach should work well, unless the space station is part of a tether system in which the station is not located at the center of mass.

CAPTIVE FREE FLYER

ORIGINAL PAGE IS
OF POOR QUALITY



TETHERED PAYLOADS

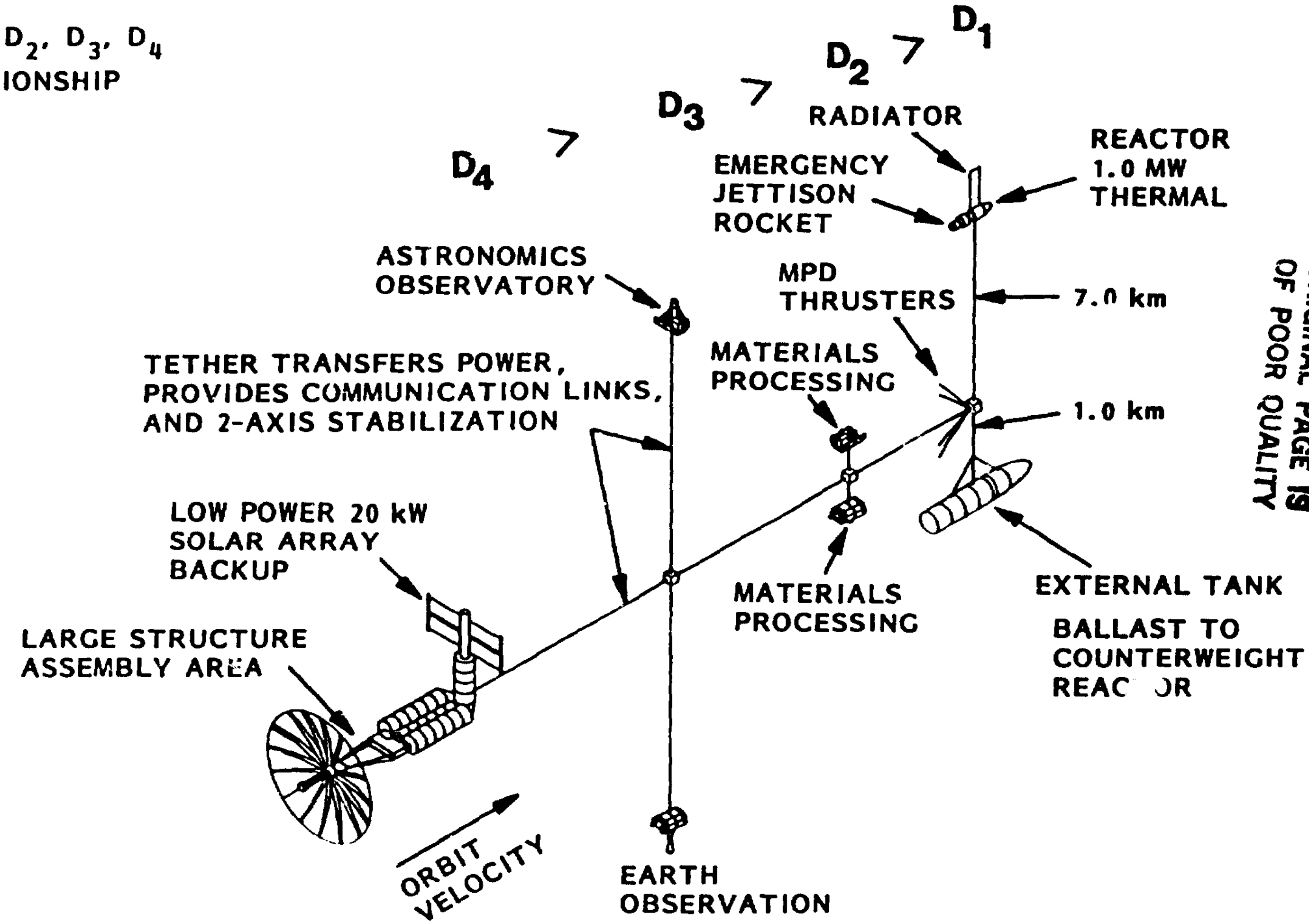
An alternative to free-flying satellites is to have individual payloads tethered to the space station. Individual satellites could be linked in a horizontal tether with the center of mass at the same orbit altitude as the space station. In addition, vertical tethers could be deployed to place payloads in the same orbit plane, but several kilometers above and below the orbit altitude.

The sketch on the facing page shows payloads tethered to the space station. The drag on the first payload is less then the drag on the second, which, in turn, is less then the drag on the third, and, in turn, all have a drag less than that of the space station. Thus the tether remains in tension. Minor perturbations may create unwelcome movement of the payloads, thereby requiring some onboard control system. The dynamic behavior would have a very long period and the disturbances would not be difficult to counteract. The reactor on the leading tether provides power to the magneto plasma dynamic (MPD) thrusters, which provide drag makeup for the entire system. By placing the reactor on a fairly long tether, with the external tank (ET) as a reaction mass, the safety of the system is enhanced, since cutting the tether puts the reactor into an elliptical orbit with an apogee at least 49 km higher. The MPD thrusters will have to be carefully positioned to avoid plume contamination on payloads, or the eight km long leading tether could be used as an Alfven engine, pulling the whole system along. Other arrangements should be considered, including systems with only payloads on tethers. In that case, drag makeup would be supplied periodically by the central station, and payloads could be reeled in during drag makeup operations.

The advantage of this concept is that payloads can be supplied power, communication, two-axis stabilization, and possible even fluid transfer on a continuous basis, through the tether system. Thus, onboard control requirements for each payload are minimal, which could significantly reduce complexity and cost. The advantages compared to a hard-docked concept are that a lower disturbance level could be achieved and contamination of the low-g environment or of the atmosphere surrounding the spacecraft would be avoided. Very long tethers could be considered if low-level artificial gravity fields are desired, and if precise control over the gravity level is required. Another advantage is that the payloads have nearly the same benefits of the low-contamination environment for a free-flying satellite, while remaining in close proximity to the space station at all times. Servicing and equipment changeout can be performed onboard the station by reeling in the tethers by trams that crawl along the tethers.

TETHERED PAYLOADS

DRAG FORCES D_1, D_2, D_3, D_4
MUST HAVE RELATIONSHIP
$D_1 < D_2 < D_3 < D4$



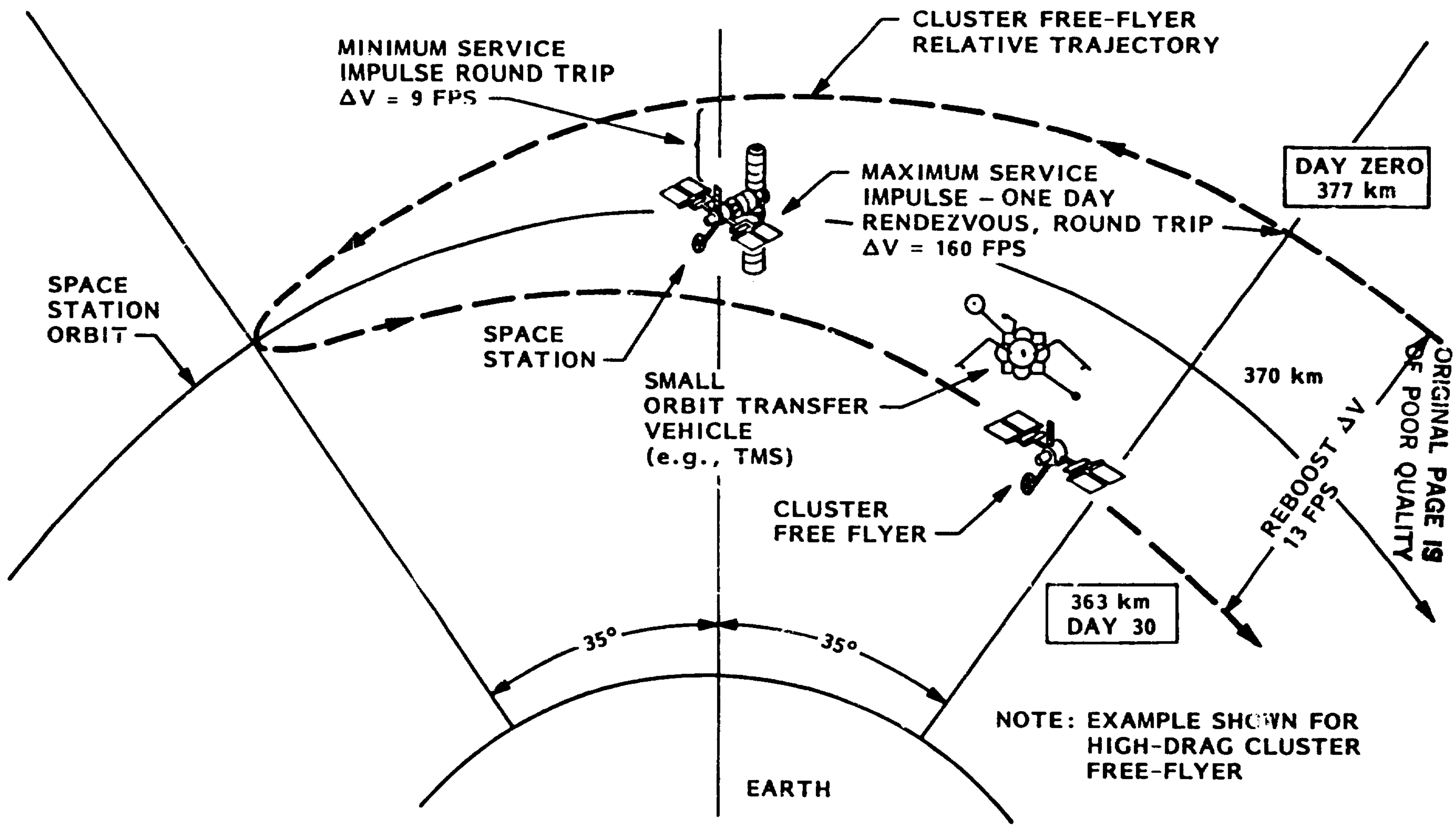
FREE-FLYER IN CIRCULAR EARTH ORBIT

Two approaches will be considered for keeping satellites in the vicinity of the space station: use of the drag characteristics of the free-flyer satellite, and use of an elliptic orbit.

The first concept (shown on the facing page) is to use the drag characteristics of the free-flying satellite (also called a cluster free-flyer) to control its position relative to the space station. At day zero, the satellite is approximately 4 nmi above the altitude of, and 35 deg in advance of the station. The 35 deg limit was selected to provide line-of-sight capability for communication between the space station and the satellite, thereby minimizing the complexity of the communication system for the free-flyer. The 35 deg limit combined with the satellite drag fixes the maximum altitude of the free-flyer. Both the station and the satellite orbit in the same direction and are coplanar. Because the satellite is initally slightly higher in altitude, its period is slightly longer and, to an observer on the station, it appears that the satellite is moving backward. Because of aerodynamic drag, the free-flying satellite gradually decreases its altitude and, after about 15 days its orbit will have decayed to that of the space station. The satellite is now 35 deg behind the space station. The orbit of the free-flyer will continue to decay and, since its altitude is now less than that of the space station, its period will be shorter. To an observer on the space station, the free-flyer appears to catch up and pass below the station. At the end of thirty days the free-flyer will be at a point 35 deg in advance of the space station. At this point, the free-flyer will be reboosted by onboard propulsion to a position identical to its starting point and the process will be repeated. Corrections will be made to the nodal drift to insure that the cluster free-flyer, on the average, remains coplanar with the space station. The cycle time for this process is 30 days for a high-drag free-flyer, and may increase to 90 or more days for a configuration with a lower ballistic coefficient. Solar flare ativity will also affect cycle time. The advantage of this process is that reboost is not required until after the 30 or more days, and thus one obtains a maximum duration, zero- g environment.

At its most extreme point the free-flyer will be about 2,500 miles from the space station. The one-day transfer can be performed using the TMS, or the satellite on-board propulsion could be used to return to the station halfway through the reboost at negligible delta V penalty.

OPTION 1-FREE-FLYER IN CIRCULAR EARTH ORBIT



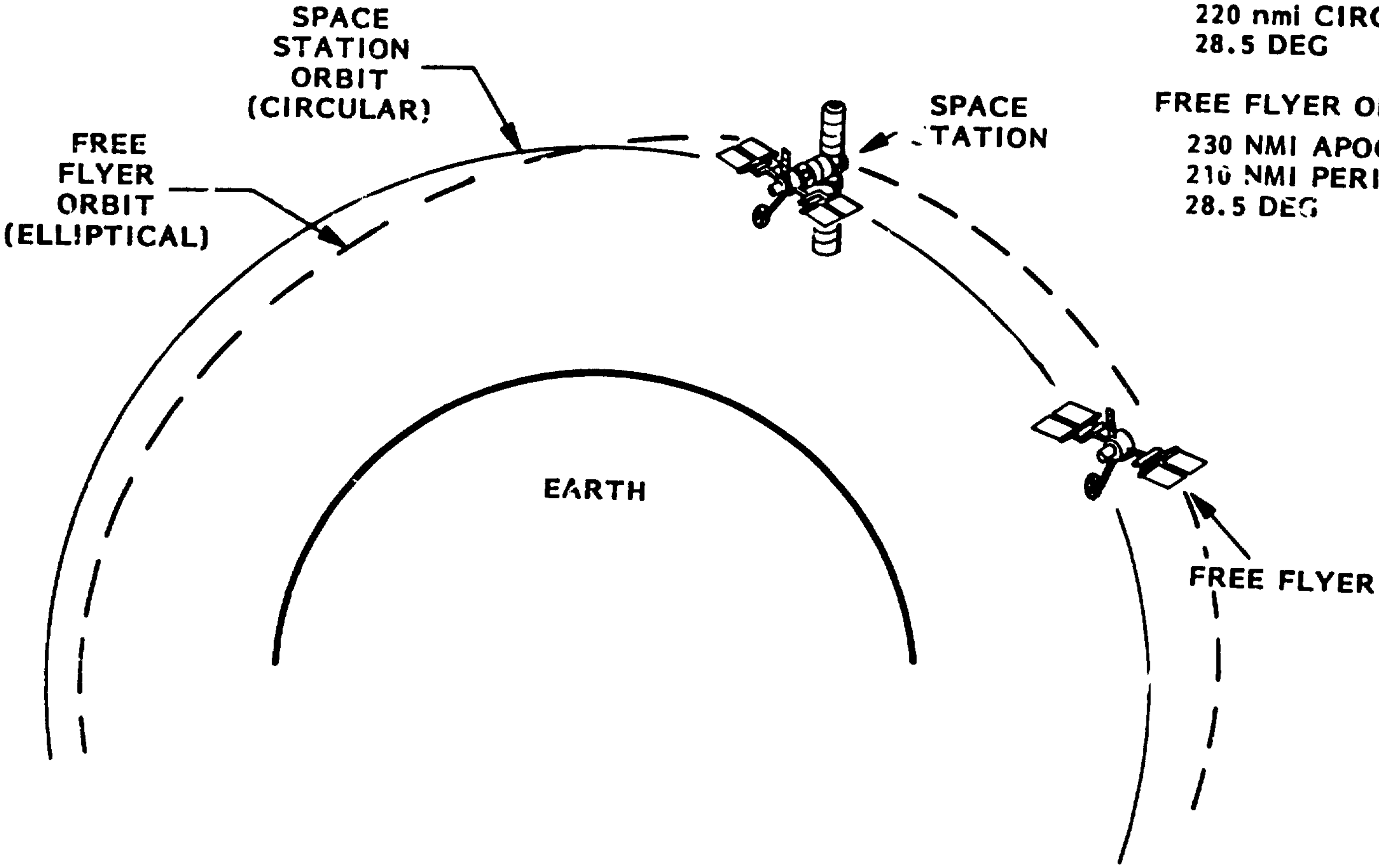
NOTE: EXAMPLE SHOWN FOR HIGH-DRAG CLUSTER FREE-FLYER

FREE-FLYER IN ELLIPTICAL EARTH ORBIT

The second means to achieve a system in which free-flying satellites orbit the space station is to place the free-flyer in an elliptical orbit of identical period to that of the space station. The apogee could be 230 nmi and the perigee 210 nmi if the station is at 220-nmi circular. To an observer on the space station, the free-flyer appears to orbit the space station. As in the preceding case, the space station is assumed to continuously maintain its orbit by use of drag makeup via onboard propulsion (e.g., conventional thrusters, ion thrusters, electromotive forces on tether).

In this mode, the free-flyer will maintain its position relative to the space station through frequent thruster firings to provide drag makeup. This may be a disadvantage of this approach compared to option 1, since the interval of undisturbed flight is probably shorter. If the drag makeup thruster firings are not detrimental to payload functions this option is advantageous since the free-flyer remains closer to the station (compared to option 1).

OPTION 2- FREE FLYER IN ELLIPTICAL EARTH ORBIT



STATION ORBIT

220 nmi CIRCULAR
28.5 DEG

FREE FLYER ORBIT

230 NMI APOGEE
210 NMI PERIGEE
28.5 DEG

ORIGINAL PAGE IS
OF POOR QUALITY

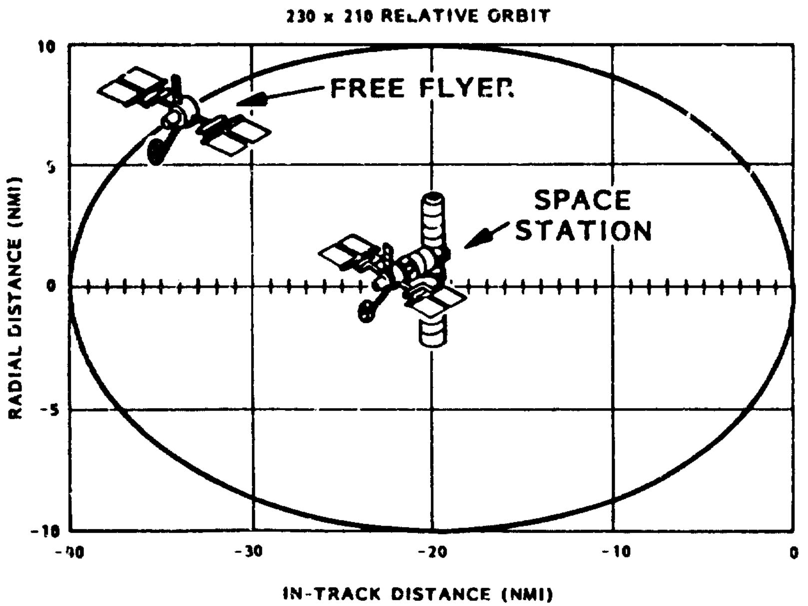
FREE-FLYER TRAJECTORY AS SEEN FROM SPACE STATION

To an observer on the space station, a free-flying satellite in an elliptical orbit having the same mean altitude (semimajor axis) as the station will appear to be in an elliptical orbit about the space station. For a free-flyer in a 28.5-deg inclination orbit with an apogee of 230 nmi and a perigee of 210 nmi, the figure on the facing page shows the relative orbit around a 28.5 deg, 220 nmi space station. Data for two cases are presented. For the apsidal alignment case, the free-flyer remains at least of 10 nmi from the station. For the case in which the station and free-flyer are periodically colocated, the two bodies will come arbitrarily close (depending on starting conditions) once each orbit. A minimum separation distance would be advisable.

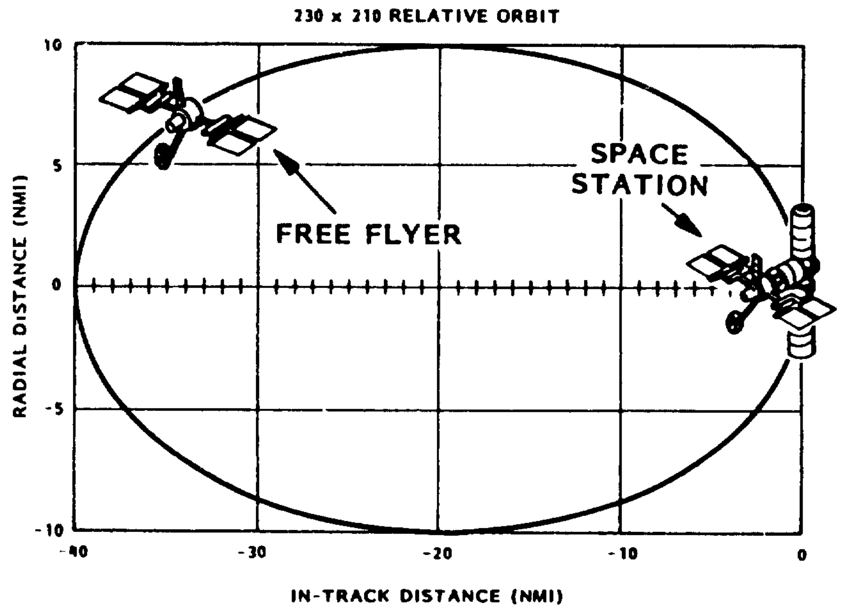
In both cases, the free-flyer is very close to the station at all times (40 nmi maximum separation in the example) and the free-flyer can be reached within 90 min (one revolution). This may have some advantages compared to the cluster free-flyer concept described earlier. However, more frequent drag makeup maneuvers are required for the elliptical orbit concept and this be a disadvantage for certain payloads.

The apogee and perigee of the free-flyer orbit can be changed, and this would simply change the magnitude of separation distance from the station. If the perigee is too low, drag effects may require excessive propellant to maintain proper orbit relative to the station.

FREE-FLYER TRAJECTORY AS SEEN FROM STATION



APSIDAL ALIGNMENT



PERIODICALLY COLOCATED

SCENARIOS FOR SPACE OPERATIONS ASSESSMENT

THESE MISSION SCENARIOS HAVE BEEN SELECTED TO COVER THE FIVE CATEGORIES OF SPACE OPERATIONS

ON-BOARD OPERATIONS

1- HARD DOCKED PAYLOADS, CAPTIVE FREE-FLYER, AND TETHERED SATELLITES
- o LARGE STRUCTURES ASSEMBLY (LARGE ANTENNA FOR SPACE RADAR)
- o ASTRONOMY PLATFORM SUPPORT (TETHERED)

REMOTE OPERATIONS

2- SUPPORT OF SATELLITES IN LOCAL STATION VICINITY
- o ASTRONOMY PLATFORM SUPPORT (AS A FREE-FLYER)

3- SUPPORT OF SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE
- o SPACE TELESCOPE MAINTENANCE
- o SPACE BASED RADAR (ITSS) MAINTENANCE

4- UNIVERSAL SUPPORT OF LEO SATELLITES
- o PROMPT SATELLITE REPLACEMENT
- o SHUTTLE CREW RESCUE VEHICLE

5- UNIVERSAL SUPPORT OF GEO SATELLITES
- o GEO SATELLITE RESUPPLY

ASTRONOMY PLATFORM - FREE FLYER

This mission description is identical in almost all respects to that for Astronomy Platform - Tethered. Obviously, the free-flying platform can be used for Earth resources experiments and operational activities as well as for astronomical purposes. The specific instrumentation and payload configurations will be different in the two cases. The primary change in this payload system from the tethered configuration is that free-flying platforms now require onboard attitude control, drag makeup, propulsion capability, communications, power, and docking/berthing/capture features. This payload platform is considerably more sophisticated than the tether system.

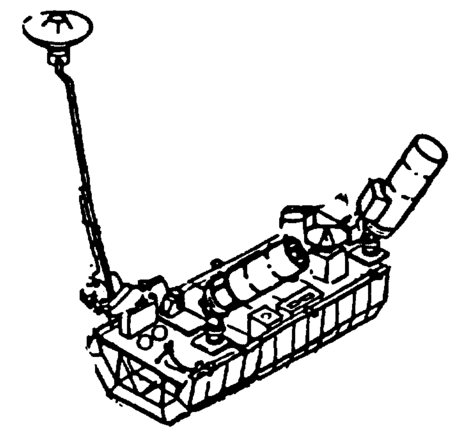
The use of free flyers as opposed to tethered systems for payload support will affect space station architecture. For a tethered system, payloads can be reached by "simply" reeling in the tether. No additional orbit transfer system is required. For a free-flying system, a small orbit transfer vehicle (OTV) such as a TMS will be required. In addition, a space to berth the payload will be required, perhaps a different area than the service area for Shuttle-based payloads.

This payload mission scenario is generic in the sense that many different types of user can take advantage of space-based servicing and would want payloads to remain in close proximity to the space station (e.g., development platforms for sensors, material processing research facilities, and astronomical observatories such as SIRTF. The user community for this class of payloads is not well defined since users have not defined their requirements beyond statements of general interest. The division between hard-docked and free-flying payloads has not been made in most cases.

ASTRONOMY PLATFORM FREE FLYER

SYSTEM DESCRIPTION:

1. PURPOSE:
   - ASTRONOMY PLATFORMS – OBSERVE PLANETARY AND CELESTIAL PHENOMENA
   - MMS DERIVITIVES – EARTH RESOURCES EXAMINATION, SPACE EVALUATION, SOLAR OBSERVATION AND EARTH-SUN STUDIES
2. LIFETIME: 5 TO 15 YEARS (INCLUDING SERVICING)
3. LAUNCH AND TRANSFER VEHICLE:
   - SHUTTLE – S/C TO ORBIT
   - SHUTTLE-SPARES/FLUIDS TO STATION
   - SHUTTLE - SPARES/FLUIDS FOR SERVICING (PRE-STA ERA)
   - P/L HANDLING UNIT (TMS XFER TO/FROM STA)
4. OPERATIONAL LOCATION: LEO AT 28.5° AND 10 NMI FROM STATION ALT WITHIN ±35° (IN PLANE) FROM STATION
5. TOTAL MASS AT OPERATIONAL LOCATION: APPROX 15 TO 25 KLB
6. AVERAGE OPERATIONAL POWER: TBD
7. DESIRED INITIAL OPERATING DATE: VARIES FROM 1984 TO 1988 +
8. GENERAL NEEDS:
   - ON-ORBIT SERVICING
   - CAPTURE AND HOLDING/POSITIONING FOR SERVICING
   - SPARES AND FLUIDS RESUPPLY
   - POTENTIAL USE OF P/L HANDLING UNIT
   - CHECKOUT DATA RATE OF 15 TO 25 KBS
   - PHYSICAL CHARACTERISTICS: 8 TO 14.5′ DIAM, 10 TO 45′ LONG, & ARRAYS UP TO 20′ EA
   - COMM/DATA LINES: S/C TO TDRSS (UP AND DOWN LINK), POSSIBLE STATION LINK



SPACE STATION PROGRAMS

CATEGORY 3

-SUPPORT OF SATELLITES IN NEARBY INCLINATION AT NODAL COINCIDENCE

EXAMPLES:

- SPACE TELESCOPE
  - SCHEDULED MAINTENANCE
- ITSS SPACE-BASED RADAR
  - SCHEDULED MAINTENANCE

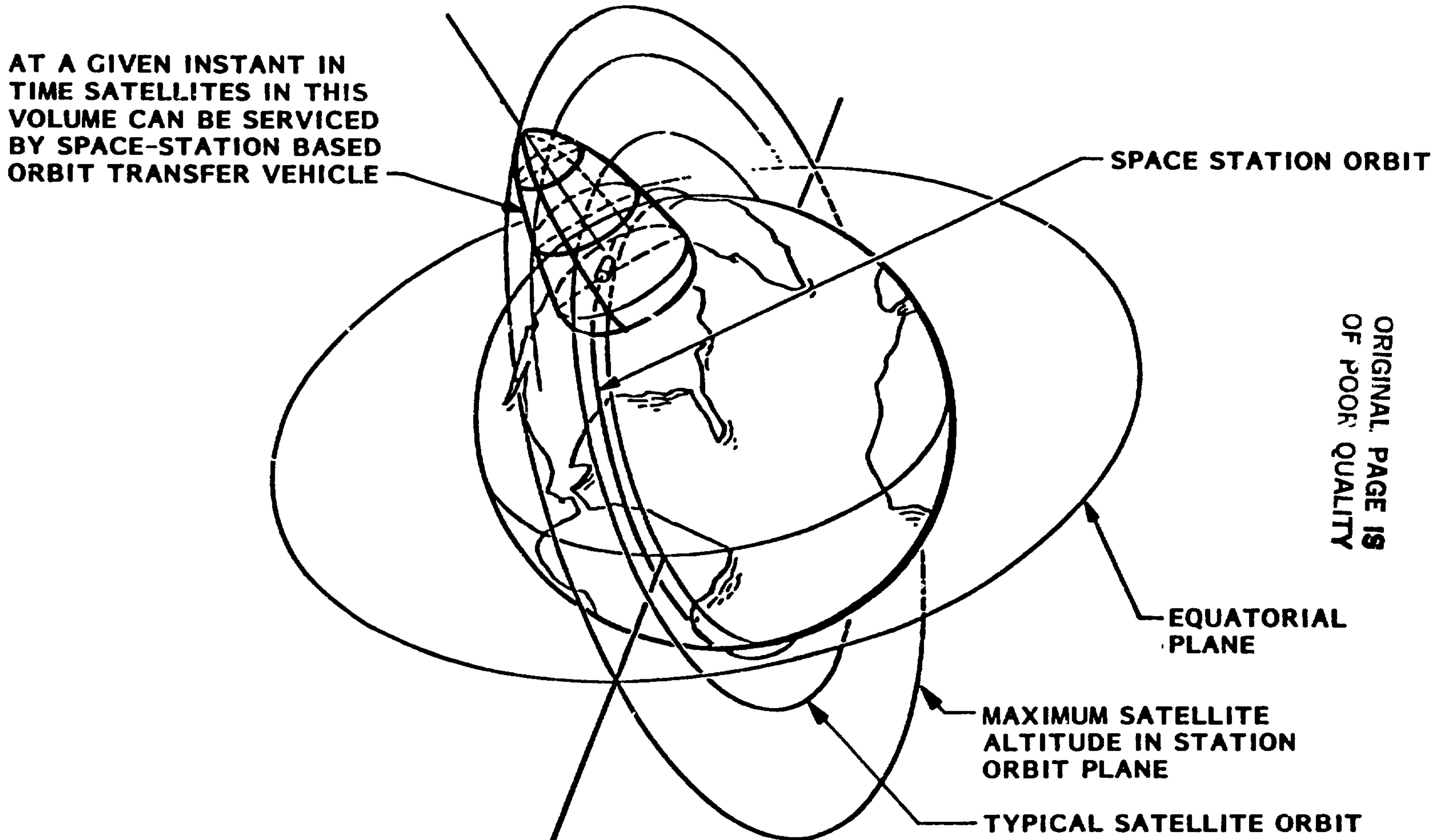
Lockheed

SPACE-BASED SATELLITE SERVICING ENVELOPE

The operational capability of an OTV is a function of its total impulse (controlled by the propellant and engine configuration), the vehicle's inert weight, presence or absence of an aerobraking system, payload to be carried, and whether the payload is to be transferred in a placement mission, a retrieval mission, or a combination of both. Given these characteristics, one can compute the volume of space that can be reached by the specific OTV. All satellites within that volume could be supported by the space station with a space-station-based OTV. This assumes, of course, that the satellite is designed to be serviced or otherwise supported by the space station.

Specific satellites passing through the service volume of the OTV will change as a function of time. Understanding this change is essential to define the capabilities and usefulness of space-based satellite servicing. In this section, we will consider OTVs comparable to the Centaur wide body, modified as a reusable system. For energy levels required for orbit transfer at nodal coincidence, aerobraking systems are beneficial, but not required. A reusable OTV is highly desirable for economic reasons.

SPACE-BASED SATELLITE SERVICING ENVELOPE AT A GIVEN INSTANT OF TIME

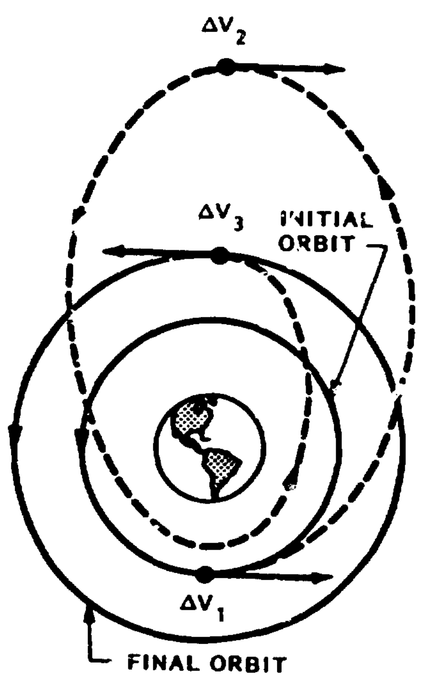


ORBITAL TRANSFERS WITH AEROBRAKING

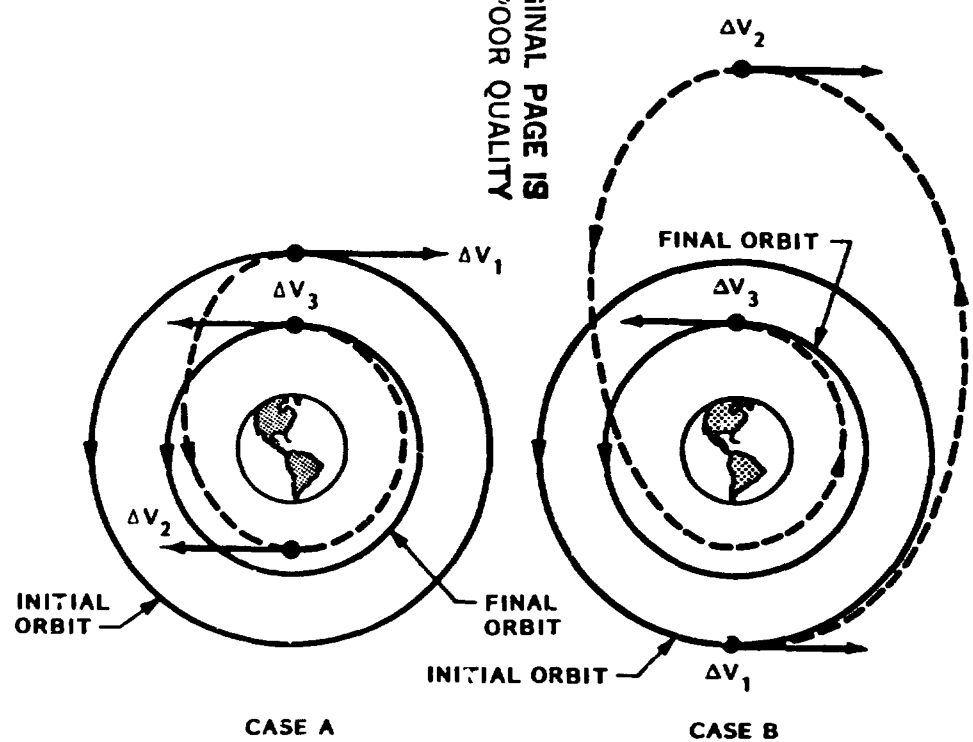
Aerobraking is an emerging technology that offers great potential for expanding the capability of OTVsby increasing the usable range without increasing propellant requirements. Preliminary studies have been performed by several contractors and NASA centers and, based on available data, it is reasonable to assume that an aerobraking system would add approximately 3,000 lb. to the inert weight of the OTV. This weight increase is offset by a substantial gain in delta velocity during orbit transfer. The actual benefit from the aerobraking maneuver depends on details of the specific orbit transfer. Studies indicte that the maximum gain from aerobraking is limited to 7,000 ft/sec. and this limit has been used in the analysis which produced the results displayed in the following pages.

Aerobraking can be used on both ascent and return transfers as shown on the facing page. For low-energy transfers, the Hohmann two-burn trajectory provides the minimum energy transfer. In this regime, aerobraking is useful only on descent (OTV return, case A); a modified two-burn trajectory is used, with most or all the intermediate burn energy coming from aerobraking. As energy levels increase, the three-burn trajectory becomes more economical (generally when the plane change exceeds 25 deg.or so) and a more complex orbit transfer path is followed. Aerobraking in this regime to reduce the energy required for both ascent and return (see payload placement and OTV return, case B). The apogee is increased as energy requirements for the transfer are increased (e.g., making large plane change). Ultimately, the unconstrained transfer involves a second burn at infinity and the transfer time becomes infinite. In the analysis contained here, the apogee was limited to 50,000 miles to constrain the orbit transfer time to 35 hr. maximum. Allowing the apogee increase would have only a modest effect on the results contained herein and would not alter any trends or conclusions reached.

ORBITAL TRANSFERS WITH AEROBRAKING



PAYLOAD PLACEMENT



OTV RETURN

TYPICAL PROPELLANT WEIGHT VERSUS DELTA VELOCITY FOR A 10,000-LB PAYLOAD

The propellant required to achieve a given change in velocity is a function of the OTV characteristics and payload to be carried. On the facing page, data are shown for an OTV with an inert weight of 3000 lb for the basic structure and equipment plus a propulsion system weight equal to 0.11 times the propellant weight. This is equivalent to a mass fraction of 0.87 for high propellant weights and to 0.70 for small propellant loads. This is consistent with a design for a cryogenic transfer vehicle with no provision for aerobraking. Another set of curves is shown for an OTV with the structure and equipment weight increased to 6000 lb. The added inert weight is to account for an aerobraking system. These figures represent typical capabilities and a specific design will yield somewhat different results. The specific impulse of 440 is consistent with current capabilities for a cryogenic propulsion system.

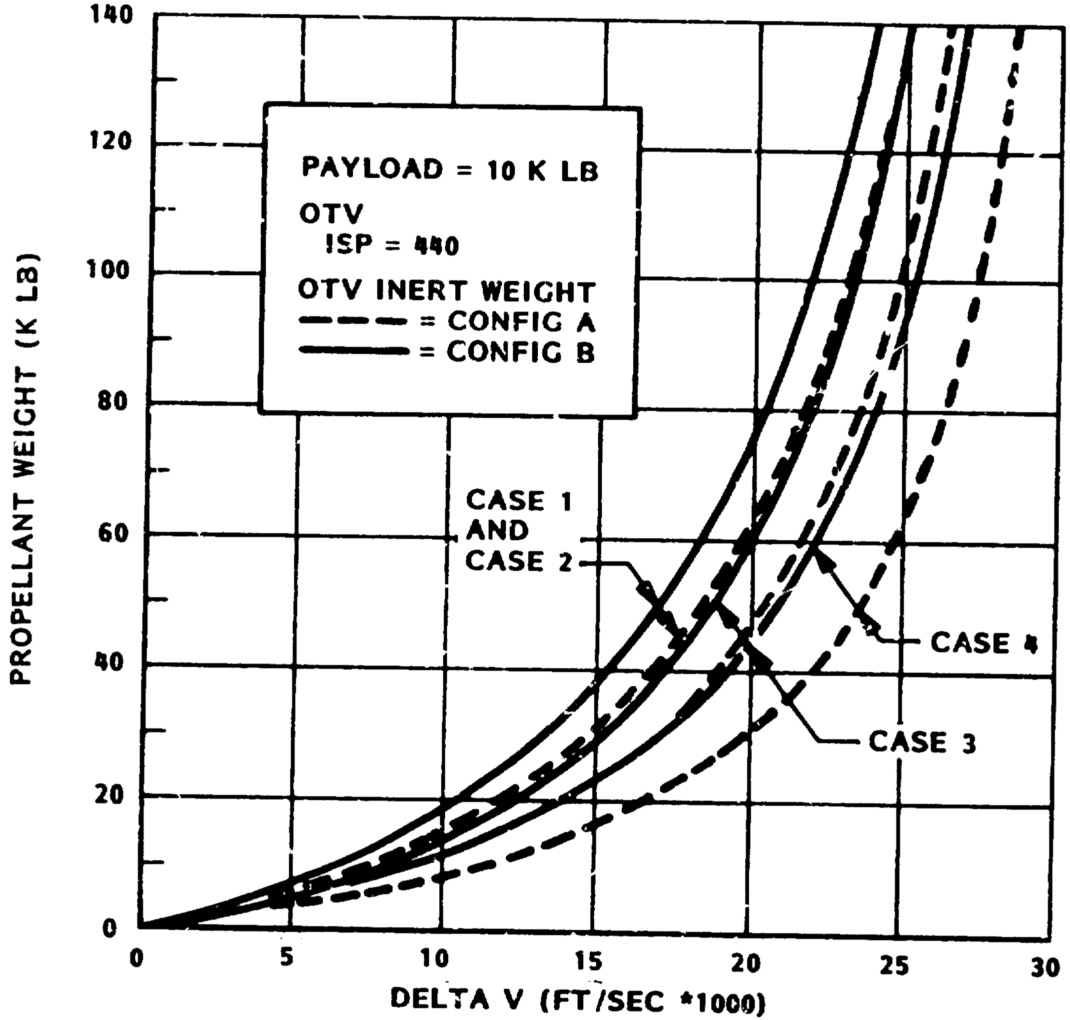
Four cases are examined: ascent and return with a 10-klb payload, ascent empty and return with a 10-klb payload, ascent with a 10-klb payload and return empty, and a one-way transit (ascent only) with a 10-klb payload.

In combining the curves for cases 1 and 2, it is assumed that the delta V for a one-way ascent is half that for roundtrip cases. For example, if a one-way transfer, case 1, requires 10,000 ft/sec , then cases 2, 3, and 4 require 20,000 ft/sec. The quantity of propellants for cases 1 to 4 are then 19, 75, 60, and 45 thousand pounds, respectively, for an OTV with aerobraking.

The 10-klb payload was selected because it is representative of small payloads of interest to science, applications, and commercial research users. It is also typical of a minimum weight for a manned capsule.

SPACE STATION PROGRAMS

PROPELLANT WEIGHTS VS ΔV FOR 10K LB PAYLOAD



CASE

1 – ONE WAY (ASCENT) WITH PAYLOAD

2 – ASCEND WITH PAYLOAD, RETURN WITH PAYLOAD

3 – ASCEND EMPTY, RETURN WITH PAYLOAD

4 – ASCEND WITH PAYLOAD, RETURN EMPTY

OTV INERT WEIGHT

CONFIG A

STRUCTURE, EQUIPMENT WITHOUT AEROBRAKE 3,000 LB

PLUS

PROPULSION SYSTEM MASS FRACTION = 0.90

CONFIG B

STRUCTURE, EQUIPMENT WITH AEROBRAKE 6,000 LB

PLUS

PROPULSION SYSTEM MASS FRACTION = 0.90

EXAMPLE:

CONFIG B WITH 45 K LB PROP.

STRUCTURE, ETC.	6,000 LB
PROPULSION SYS	5,000 LB
TOTAL	11,000 LB

Lockheed

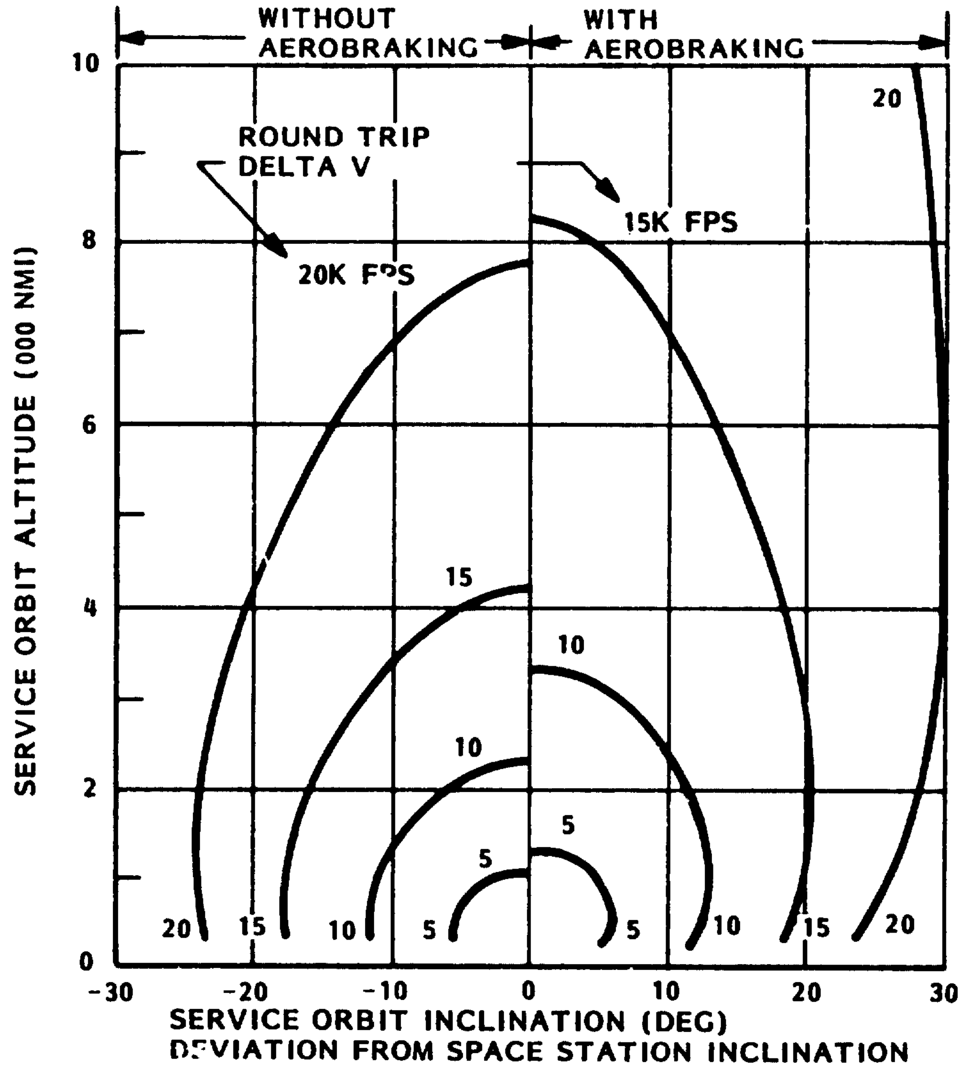
MINIMUM DELTA VELOCITY REQUIRED FOR ROUND TRIP BETWEEN SPACE STATION AND SATELLITE

Contours of constant delta V are shown on the facing page for roundtrip orbit transfers involving a combination of altitude and inclination change. These computations assume that the space station is at 220-nmi circular orbit. These data are valid for any space station inclination.

For cases in this regime, aerobraking is effective only on return missions, because orbit transfer involves comparatively small plane changes. The added complexity and weight of the aerobraking systems must be traded against propellant saved. For servicing missions up to 15-deg plane change at low altitude (less than a few thousand nautical miles), aerobraking systems are not required and they do not appear to offer dramatic enhancement. Cases in which aerobraking has a dramatic impact will be discussed later.

These curves assume there is no delay at the satellite operational altitude. Since the transit time is on the order of hours each way, the effect of nodal drift is negligible. If there is an extended delay to perform operations on the satellite at operational altitude, the energy required for the roundtrip transfer can be substantially affected, as discussed in the following pages.

MINIMUM DELTA V REQUIRED FOR ROUND TRIP BETWEEN SPACE STATION AND SATELLITE



SPACE STATION:
220 NMI CIRCULAR

NO DELAY AT SERV. ORBIT

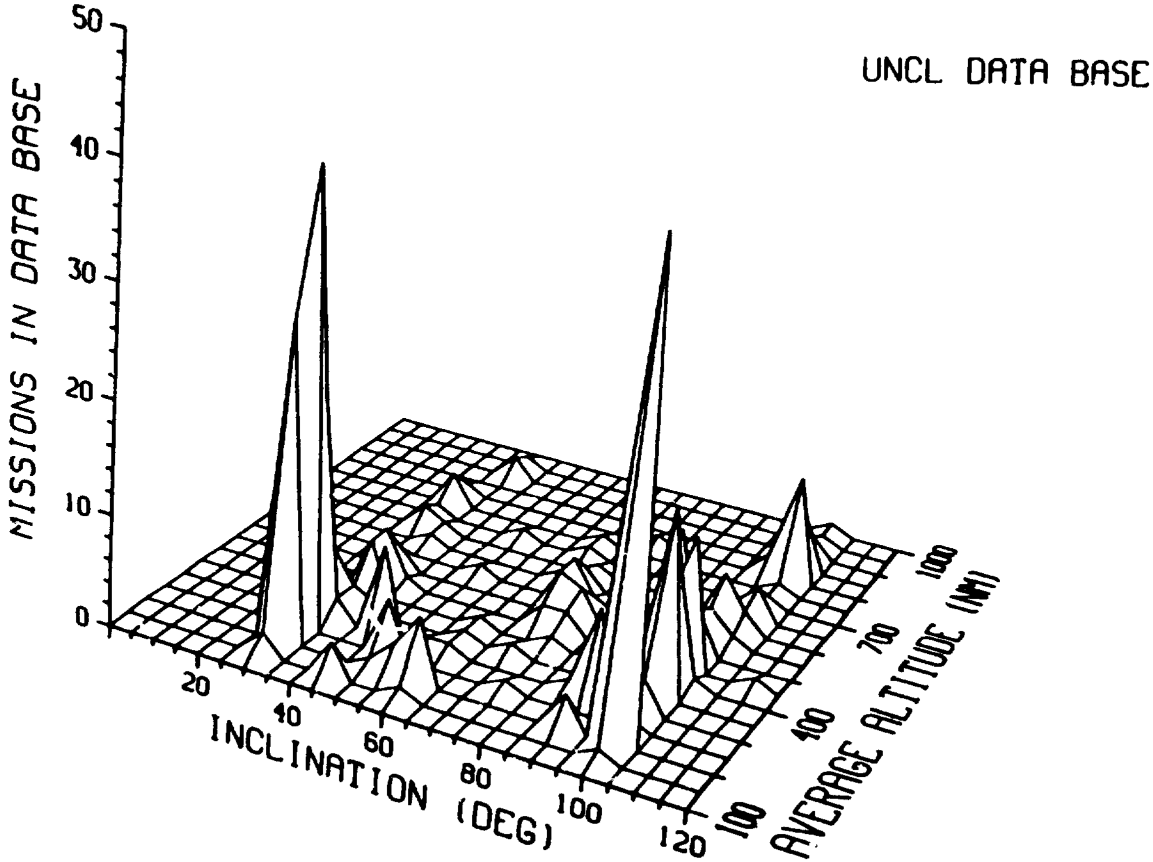
ORIGINAL PAGE IS OF POOR QUALITY

PLANNED MISSION DISTRIBUTION

A mission model has been developed to determine the number of satellites to be in orbit from 1982 through 1992. Satellites were categorized by operational inclination and altitude and the number of satellites in each category is displayed on the facing page. Many users place satellites in specific orbits for specific requirements; however, most civilian satellites are contained in two orbits (28.5 and 98 deg). As discussed earlier, scheduled maintenance and repair for satellites is done most efficiently at nodal coincidence; energy limitations require that a space station be at 28.5 deg and 90 to 98 deg if most civilian satellites are to be serviced from a space-based system.

This mission model containing 655 satellites is speculative because not all missions are approved or under way. The fact that most of satellites cluster in two inclinations indicates that many satellites can be serviced from a space-based system and that it makes sense to consider servicing as a primary function of a space station. An economic trade study comparing Space-Shuttle-based servicing with space-station-based servicing shows a substantial cost advantage to the space station system even if only a few satellites are serviced in a given year.

PLANNED MISSIONS DISTRIBUTION



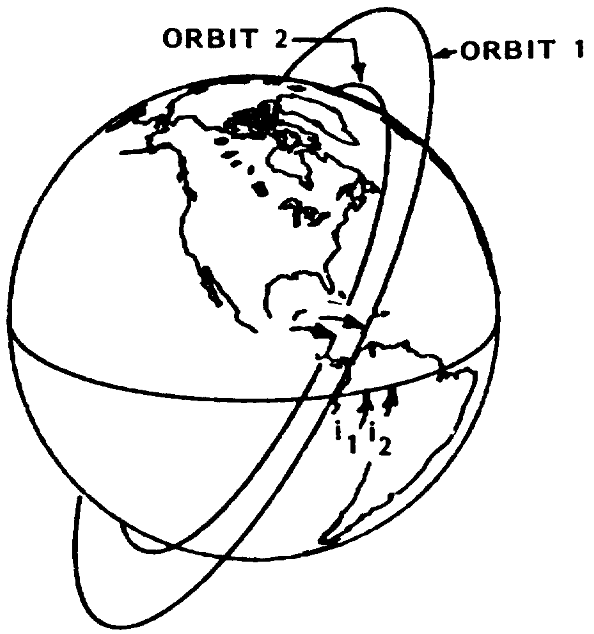
EFFECT OF NODAL DRIFT OF CIRCULAR ORBITS

From our discussions, we found that many users did not recognize the effect of nodal drift and its impact on energy required for orbit transfers. The minimum energy transfer between satellites in two different orbits occurs when both orbits cross the equator at the same point (nodal coincidence). The relationship between two orbits changes as a function of time, and the interval between nodal coincidences can be substantial.

Two satellites with orbits at the same inclination but different altitudes also experience relative nodal drift. The plane change required to transfer from one orbit to another at a different altitude but with the same inclination will vary from zero at nodal coincidence to a maximum equal to twice the inclination when the satellites are 180-deg. out of phase. The minimum plane change to transfer from a satellite in one orbit to a satellite in another at a different inclination occurs at nodal coincidence and is equal to the difference in inclinations.

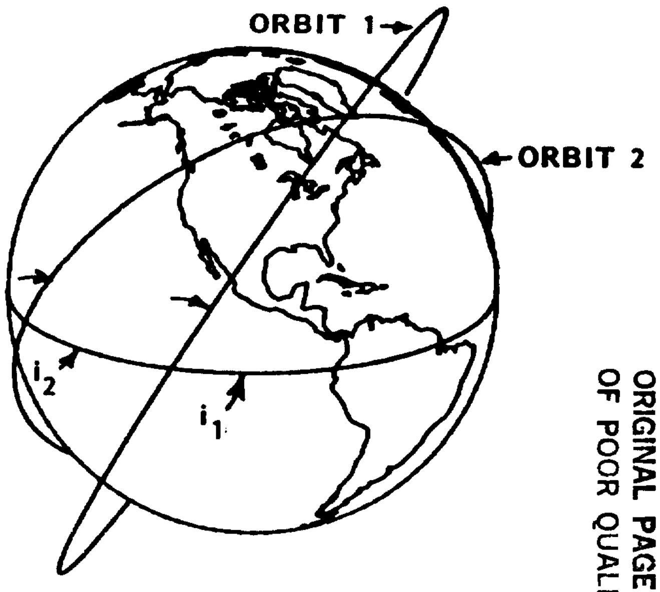
SPACE STATION PROGRAMS

EFFECT OF NODAL DRIFT OF CIRCULAR ORBITS AT SAME INCLINATION BUT WITH DIFFERENT ALTITUDES



TIME $t = 0$

ORBIT 1 AND ORBIT 2 ARE COPLANAR
BOTH HAVE SAME INCLINATION ($i_1 = i_2$)



TIME $t = T$

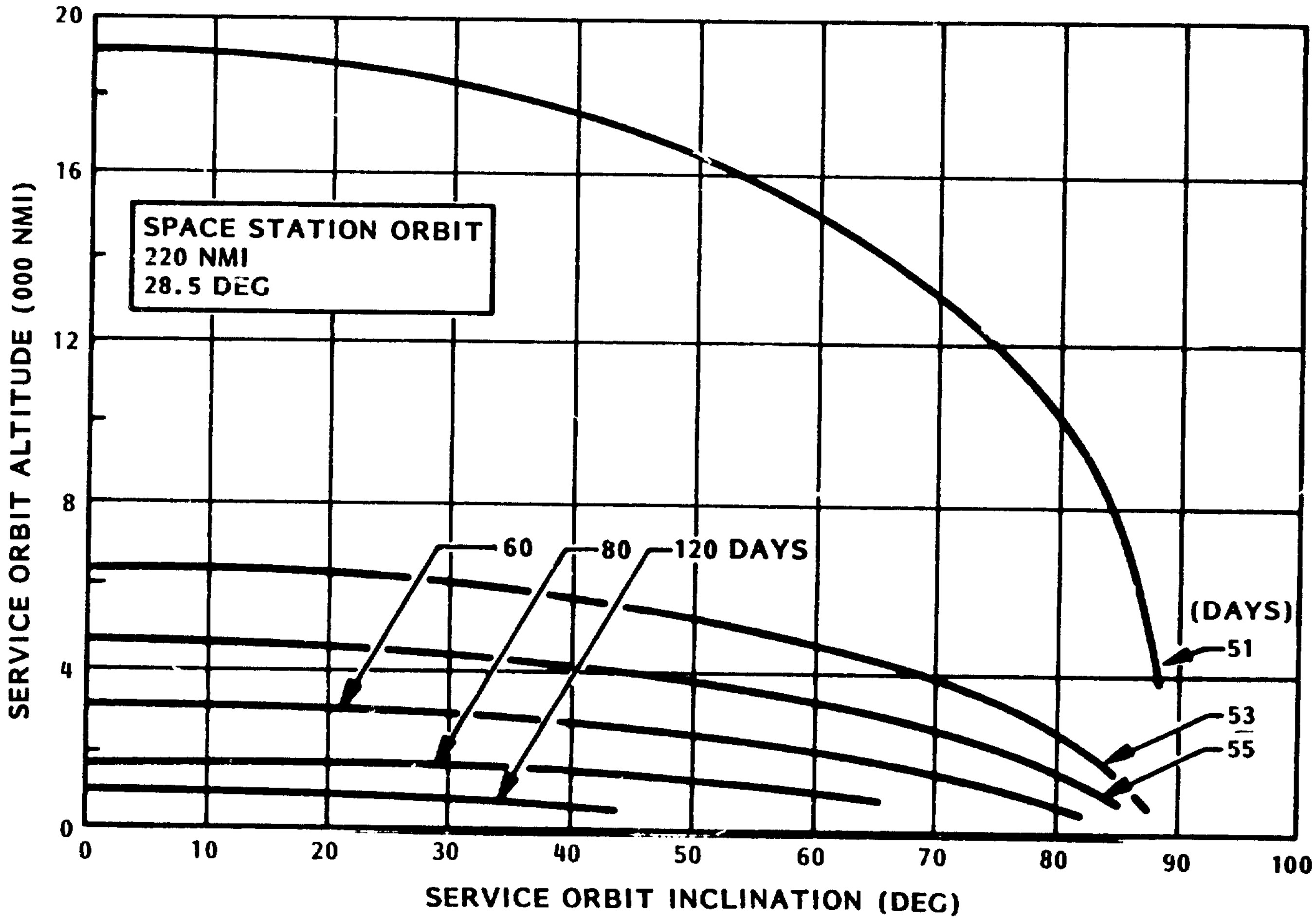
ORBIT 1 AND ORBIT 2 ARE NOT COPLANAR
BOTH HAVE SAME INCLINATION ($i_1 = i_2$)

Lockheed

INTERVAL BETWEEN NODAL COINCIDENCES OF A 28.5-DEG. SPACE STATION AND SATELLITE

The time interval between successive nodal coincidences of orbits for a space station and a satellite is a function of inclination and altitude of the space station and satellite. For a space station located at 220-nmi circular and 28.5-deg. inclination, contours of constant time between nodal coincidences are shown on the facing page. Since the nodal regression of satellites at high altitudes is very small, the minimum interval between nodal coincidences occurs with satellites in high Earth orbit. Satellites which have orbits very close in altitude to the space station have the longest interval between nodal coincidences. For this case, the minimum interval is about 50 days. For satellites in a 600-nmi orbit at 28.5-deg., the interval more than doubles. For satellites in nearly the same altitude as the station, the interval between nodal coincidences can be years. For instance, the interval for a 300-nmi, 28.5-deg. satellite is 23 months.

INTERVAL BETWEEN NODAL COINCIDENCES FOR A 28.5 DEG SPACE STATION AND A SATELLITE



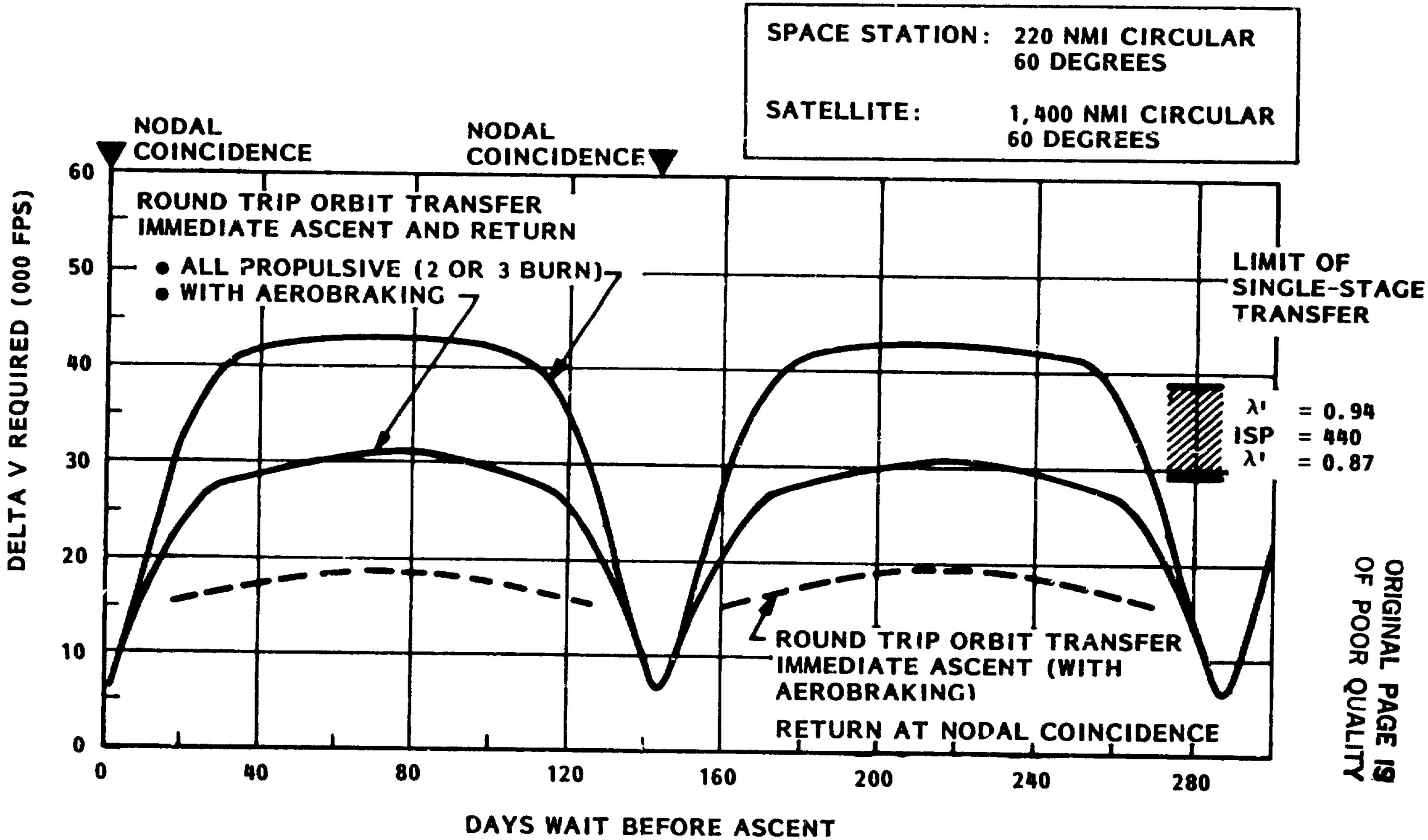
ORIGINAL PAGE IS OF POOR QUALITY

DELTA V FOR NON-OPTIMUM ORBIT TRANSFER

The chart on the facing page shows the delta V required to make an orbit transfer anytime between a space station at 220-nmi circular orbit at 60-deg, and a satellite at 1,400-nmi in a circular orbit at 60-deg. The delta V required to transfer is computed using an optimized two-or three-burn maneuver with or without aerobraking. The roundtrip energy is substantially reduced if aerobraking is used on both ascent and return maneuver. The maximum apogee is limited to 50,000 miles for the three-burn maneuvers. Higher altitudes require slightly less energy, but with increased transit time. One-way transit time varies from approximately one hour for the region around nodal coincidence to a maximum of 35 hours in regions where the roundtrip delta V exceeds 25,000 ft/sec. The transit time is essentially the same with or without aerobraking. The effect of aerobraking depends on the specific transfer; however the upper limit is a maximum 7,000 ft/sec. benefit on both ascent and return.

A minimum energy roundtrip can be realized by making an immediate ascent (required, for instance, to place a spare satellite in operation), with the return flight made at nodal coincidence. The disadvantage is that the OTV and payload (if any) to be returned must wait several months on orbit before returning to the space station. An alternative mode is to immediately return to an operational altitude serviced by the Space Shuttle; the delta V required for that transfer is the same as a transfer to the station at nodal coincidence.

DELTA V FOR TRANSFER AT NON-OPTIMUM TIME



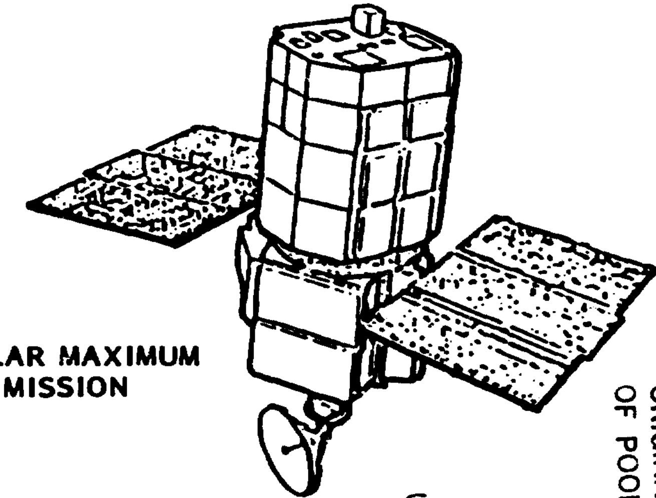
ORIGINAL PAGE IS OF POOR QUALITY

ESTABLISHING THE NEED FOR ON ORBIT SERVICING

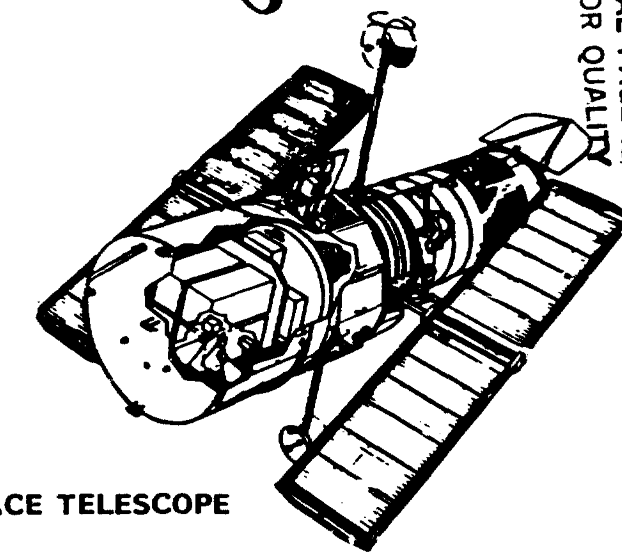
As we enter the Shuttle era, more consideration is being given to the design of satellites for servicing. Although only a few satellites currently in orbit have been designed for servicing (e.g., Solar Max), many spacecraft currently in detailed design or hardware fabrication stages (such as Space Telescope) are designed for on-orbit servicing and maintenance. As users begin to exploit the capabilities of the Shuttle and space station for servicing, more satellites will incorporate necessary hardware designs to allow on-orbit maintenance, repair, and equipment update. Some key considerations in defining the level of servicing to be accommodated are indicated on the opposite page.

ESTABLISHING THE NEED FOR ON-ORBIT SERVICING

1. RELIABILITY AND MTBF FACTORS
2. ITEMS HIGHLY SUSPECT TO MALFUNCTION BUT WITH LIMITED FLIGHT RELIABILITY DATA
3. PREVENTIVE MAINTENANCE CONSIDERATIONS
4. WEAR-OUT LIFETIMES
5. DEGRADATION LIFETIMES
6. ITEMS THAT MAY RECEIVE INADVERTENT COLLATERAL DAMAGE
7. ITEMS SUBJECT TO EMI OR OTHER 'SIGNAL' SPECTRA DAMAGE
8. INDUCED DAMAGE, E.G, LOSS OF THERMAL CONTROL AND SUBSEQUENT CHANGE OF TEMPERATURE PAST SURVIVABILITY LEVEL
9. MICRO-METEORITE PENETRATION/DAMAGE
10. CASCADING FAILURES OR POWER SURGES
11. EQUIPMENT/EXPERIMENT ITEM UPDATE/ REPLACEMENT
12. NEW PAYLOAD REPLACEMENT
13. COMPLETE SUBSYSTEM REPLACEMENT
14. ETC.



SOLAR MAXIMUM MISSION



SPACE TELESCOPE

SPACE STATION PROGRAMS

CATEGORY 4

-UNIVERSAL SUPPORT OF LOW EARTH ORBIT (LEO) SATELLITES

- ONE-WAY ORBIT TRANSFER
- TYPICAL MISSIONS
  - -ON ORBIT LAUNCH OF SPARE SATELLITE (e.g. ITSS SPACE-BASED RADAR)
  - -SPACE SHUTTLE ORBITER CREW RESCUE VEHICLE

Lockheed

DELTA VELOCITY REQUIRED FOR ORBIT TRANSFER AT NON-OPTIMUM TIMES (WITHOUT AEROBRAKING)

In this section, we will examine more carefully the impact of orbit transfer at non-optimal times. A particular focus will be the influence of space station location on the energy required for orbit transfer.

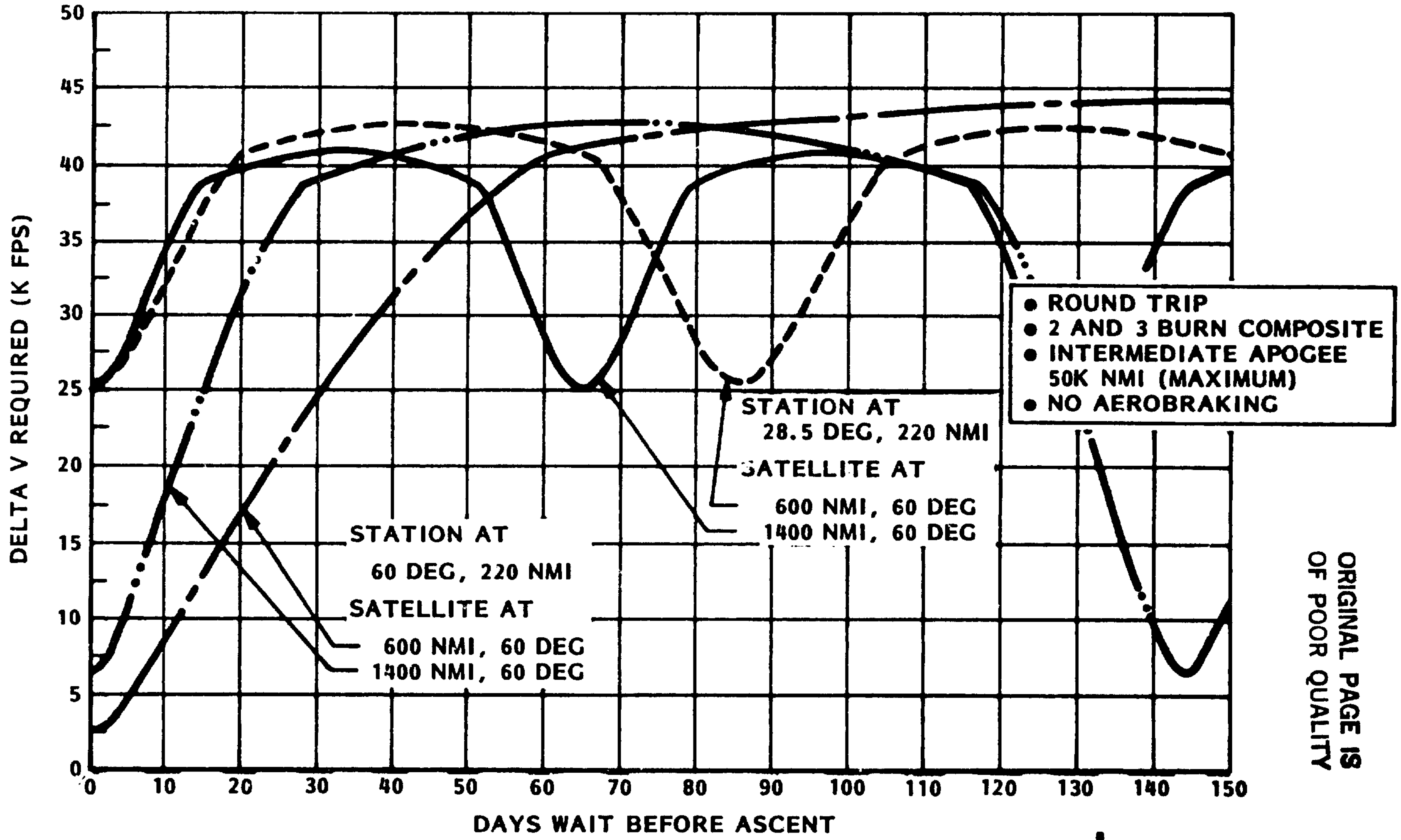
Four sets of curves are presented in the figure on the facing page. The data for the delta V required to transfer from a station at 60-deg, 220-nmi, to a satellite at 60 deg, 1400-nmi are identical to the data shown earlier. The energy required to transfer to a 600-nmi satellite is also shown; interestingly, although the energy at nodal coincidence is significantly lower, the maximum energy for orbit transfer at non-optimum time is essentially the same, independent of spacecraft altitude. Also, if the space station were at 28.5-deg the energy required for orbit transfer to the 60-deg satellite location at nodal coincidence is substantially increased but the energy required for transfer at a non-optimum time is not significantly different, and, in fact, is lower than the peak energy required from the 60 deg station.

Note that these non-optimal transfers use a three burn trajectory with the intermediate apogee set not to exceed 50,000-nmi No aerobraking was used in determining these roundtrip delta V requirements.

SPACE STATION PROGRAMS

ΔV FOR TRANSFER AT NON-OPTIMUM TIMES

(NO AEROBRAKING)



ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

INFLUENCE OF STATION INCLINATION ON DELTA V FOR ONE-WAY TRANSFER - CASES 1 AND 2

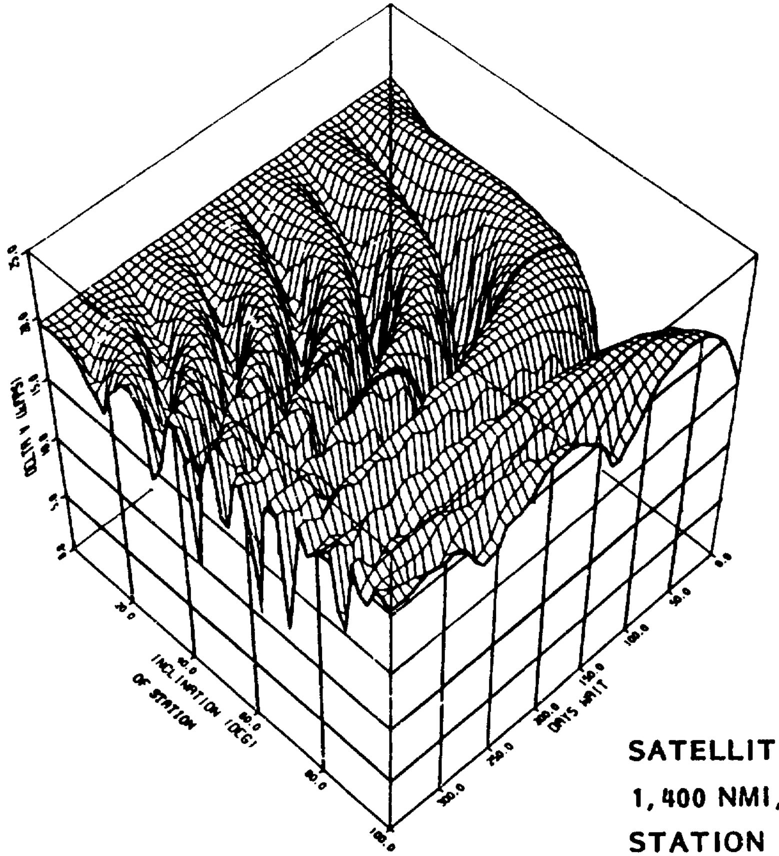
To determine the influence of station inclination on delta V required for minimum energy transfer at non-optimum times, a series of cases was examined. Space station location and time of transfer (in terms of delay after nodal coincidence) were varied while the satellite location remained at 1,400-nmi, 60-deg. inclination. The one-way delta V was computed for designs with and without aerobraking (cases 1 and 2).

As shown, the minima follow a regular pattern, creating valleys in the surface. The most significant fact is that the maxima in case 1 (no aerobraking) are generally bounded by a 20,000 ft/sec. upper bound regardless of station inclination. The behavior for case 2 (with aerobraking) is essentially the same except that the upper bound is about 15,000 ft/sec.

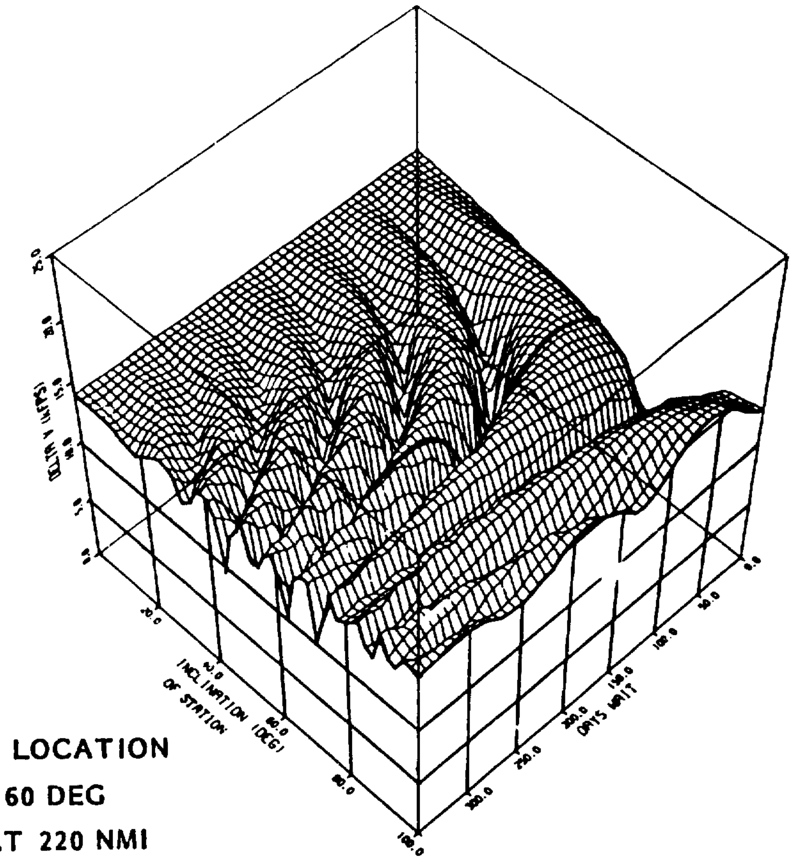
The heavy line on this and the subsequent figures emphasizes the delta V required to make the transfer from a station in the same inclination as the satellite.

INFLUENCE OF STATION INCLINATION ON ΔV

ONE WAY TRANSFER - CASE 1
NO AEROBRAKING



ONE WAY TRANSFER - CASE 2
WITH AEROBRAKING



SATELLITE LOCATION
1,400 NMI, 60 DEG
STATION AT 220 NMI

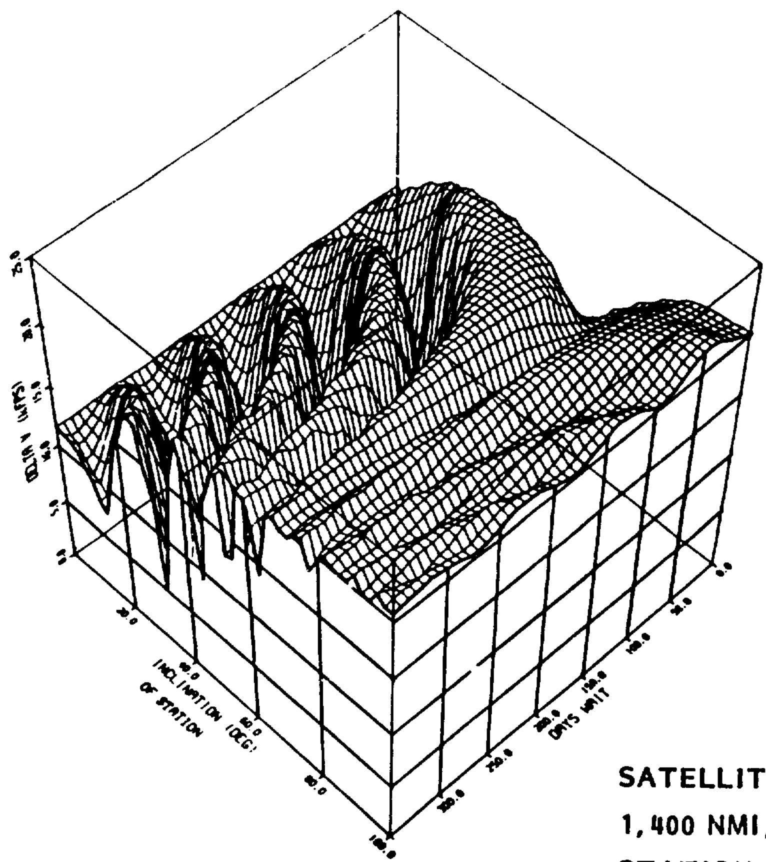
ORIGINAL PAGE IS
OF POOR QUALITY

INFLUENCE OF STATION INCLINATION ON DELTA V FOR ONE-WAY TRANSFER - CASES 3 AND 4

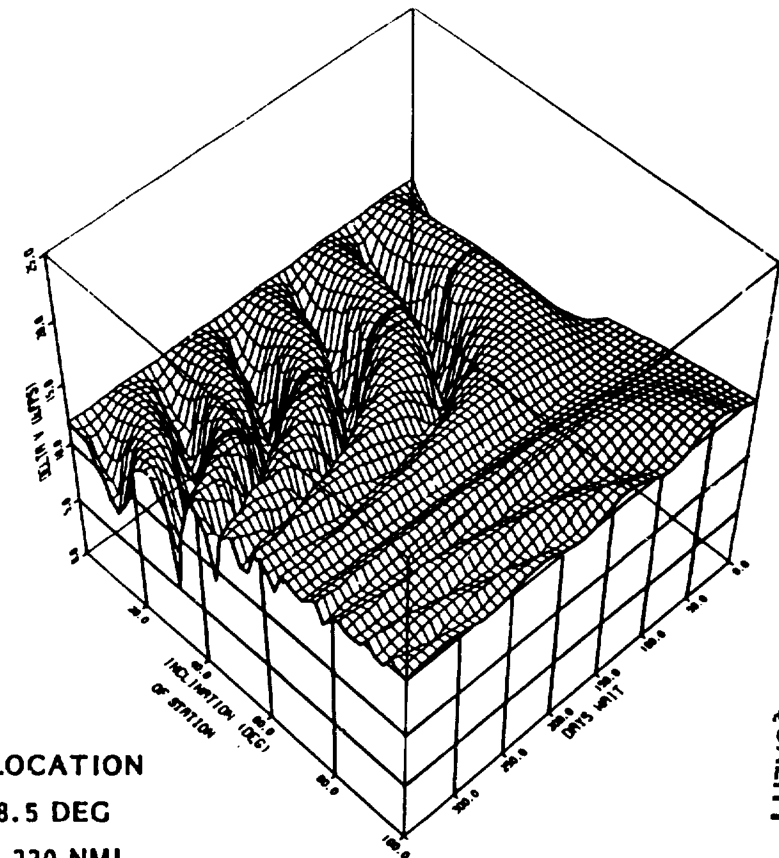
The objective here is to examine the influence of changing satellite location. In the preceding two cases, the satellite was at 60 deg., whereas in this case the satellite is at 28.5 deg. Its altitude remains unchanged at 1,400-nmi. The energy required to reach this satellite from low-inclination space stations is significantly less than that required to reach the satellite from higher inclination orbits. Significantly, however, the surface is bounded by a maximum limit of about 20,000 ft/sec for systems without aerobraking, and about 15,000 ft/sec for systems with aerobraking, just as in cases 1 and 2.

INFLUENCE OF STATION INCLINATION ON ΔV

ONE WAY TRANSFER - CASE 3
NO AEROBRAKING



ONE WAY TRANSFER - CASE 4
WITH AEROBRAKING



SATELLITE LOCATION
1,400 NMI, 28.5 DEG
STATION AT 220 NMI

ORIGINAL PAGE IS
OF POOR QUALITY

SHUTTLE CREW RESCUE VEHICLE

Some may question why a shuttle crew rescue mission is considered in a section on LEO satellite servicing. An orbiting shuttle is, in fact, a satellite, and crew rescue from a disabled vehicle is indeed a high priority mission, quite appropriately discussed in a section on satellite servicing.

At the present time, the only means to rescue the crew of an orbiting disabled Space Shuttle is to launch another Shuttle orbiter. Although onboard reentry rescue capsules have been considered, this approach has the disadvantage that the reentry capsule takes weight and volume away from available payload. However, the presence of the space station allows an alternative concept to be implemented in which the Shuttle crew rescue vehicle is permanently based at the space station. Several approaches have been considered in previous studies, including rescue capsules for each crewperson. The concept discussed here considers a single vehicle sized for a crew of 10. This vehicle could be boosted to any orbit with the combination of two OTVs in a fashion similar to that used for the ITSS space- based radar satellite replacement. The rescue capsule is estimated to weigh less than 24,000 lb to carry a crew of up to 10; this rescue capsule could also provide emergency support to the space station itself. The transit time will vary from 1 to 35 hours, depending on the specific location of the space station and Space Shuttle at time of use.

SHUTTLE CREW RESCUE VEHICLE

- REENTRY VEHICLE (RV) AND OTV TO BE STORED AT SPACE STATION

- RV DESIGNED FOR 10-PERSON CAPACITY
  - MAXIMUM SHUTTLE CREW IS SEVEN
  - 10-PERSON CAPACITY ALLOWS GROWTH TO SUPPORT STATION NEEDS (2 RVs, RATHER THAN ONE LARGER SIZE, USED TO SUPPORT STATION CREW TO PROJECTED SIZE OF 20 IN 1998)

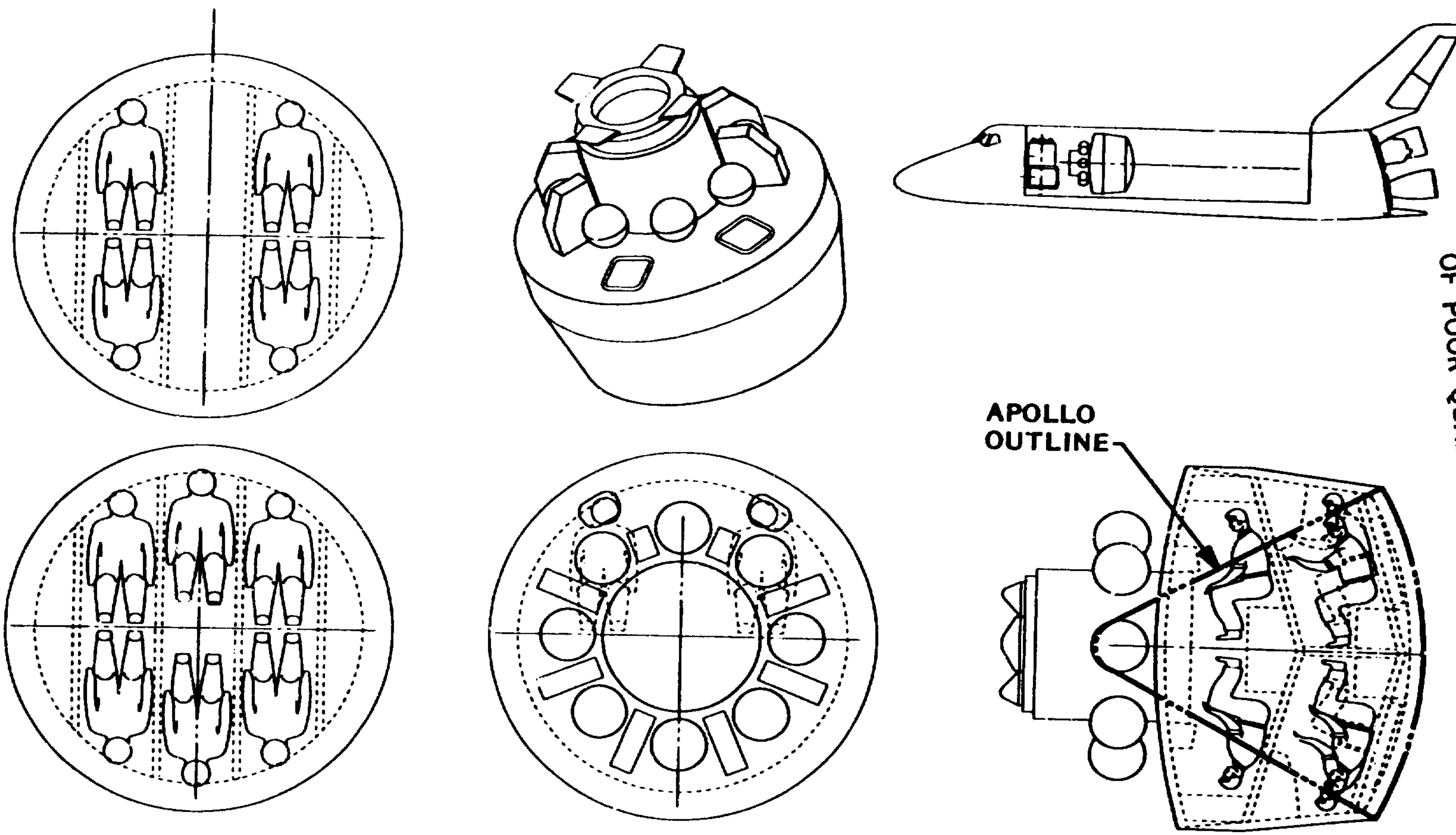
- PROPER OTV (E.G., WIDE-BODY CENTAUR WITH AEROBRAKING) CAN TRANSFER RV TO ANY ORBIT FROM ANY STATION LOCATION
  - STATION AT 28.5 DEGREES COULD SUPPORT RESCUE OF ORBITER CREW EVEN AT 98 DEGREES
  - FIRST "TRUE" SAFE-HAVEN FOR ORBITER CREW
  - TRANSIT TIME IS APPROXIMATELY 35 HR
  - APPROXIMATELY 70,000 LB OF CRYOPROPELLANT REQUIRED

- RV COULD ALSO SERVE AS MANNED CREW AND CARGO TRANSFER VEHICLE

TEN-PERSON RESCUE VEHICLE

A Shuttle-compatible rescue vehicle for 10 persons is shown in the sketch on the facing page. This configuration was developed using existing technology (including an Apollo-type heat shield), providing volume for the crew and necessary consoles and equipment. No detailed design has been developed, although a preliminary estimate indicates such a system would weigh about 24,000 lb.

10-PERSON RESCUE VEHICLE

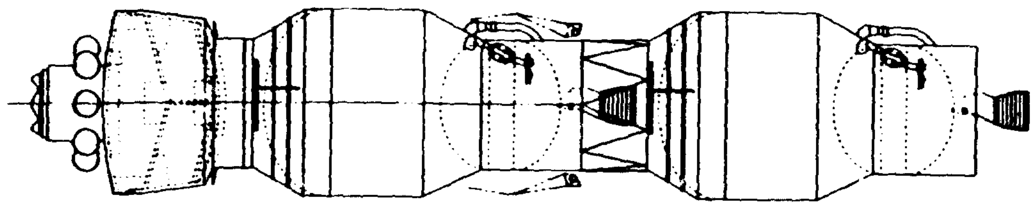


OTV RESCUE CONCEPT

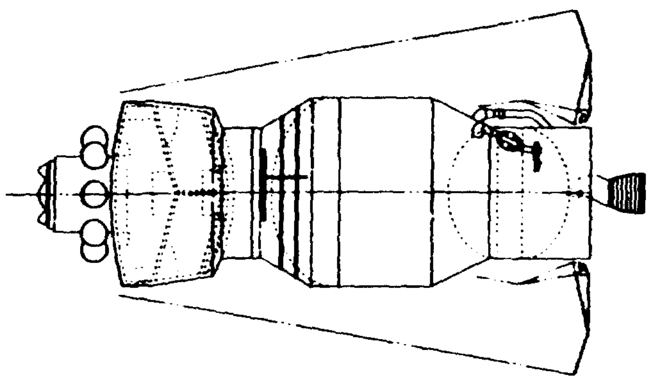
By using two centaur OTVs in tandem with aerobraking on the second stage OTV a delta V of 18,000 feet per second can be obtained. If propellant is retained in the first and second stage to allow the first stage to return to the station and to allow the second stage to return to a 220 nautical mile orbit for later pick-up by the space shuttle, the delta V of the system is reduced to 16,500 feet per second. This is still adequate to reach any LEO position from any space station location, provided aerobraking is used as indicated.

24K LB PAYLOAD - ONE-WAY TRANSFER

REUSABLE CENTAUR-TYPE OTV CRYOGENIC PROPELLANT (ISP = 440)



		SECOND STAGE	FIRST STAGE
PAYLOAD	24,000 LB		
PROPELLANT		45,000 LB	45,000 LB
INERT WEIGHT		6,640	6,640
AEROBRAKING		3,000	0
INTERSTAGE	INCL IN P/L	0	360



ORIGINAL PAGE IS OF POOR QUALITY

STAGE	ΔV (K FPS) ASCENT	RETURN
ONE-WAY OTV		
FIRST	6.0	0
SECOND	12.0	0
TOTAL	18.0	
FIRST STAGE RETURN		
FIRST	5.4	5.4
SECOND	12.0	0
TOTAL	17.4	
BOTH STAGE RETURN*		
FIRST	5.4	5.4
SECOND	11.1	3.0
TOTAL	16.5	

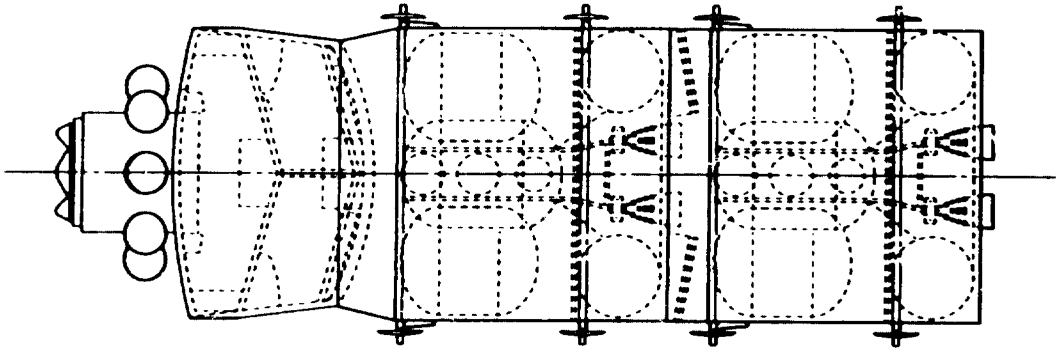
*SECOND STAGE RETURNS TO SHUTTLE-COMPATIBLE ORBIT

OTV RESCUE CONCEPT (CONTINUED)

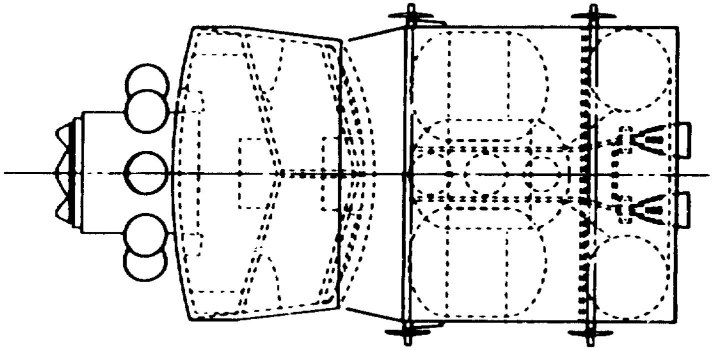
An alternative configuration using storable propellants is shown in the chart on the facing page. The propellant load has increased to 115,000 lbs and the delta V available has dropped by 1,500 feet per second, but this system still has the capability to launch to almost any location at any time. It has the advantage that the storable propellants avoid the restraints imposed by long term storage of cryogens on orbit.

SPACE STATION PROGRAMS

24K LB PAYLOAD – ONE-WAY TRANSFER
REUSABLE OTV
STORABLE PROPELLANT (ISP=340)



		SECOND STAGE	FIRST STAGE
PAYLOAD	24,000 LB		
PROPELLANT		57,570 LB	57,570 LB
INERT WEIGHT		5,080	5,080
AEROBRAKING		3,000	0
INTERSTAGE	INCL IN P/L	0	320



ORIGINAL PAGE IS
OF POOR QUALITY

ΔV (KFPS)

STAGE	ASCENT	RETURN
ONE-WAY OTV		
FIRST	5.2	0
SECOND	11.2	0
TOTAL	16.4	
FIRST STAGE RETURN		
FIRST	4.8	4.8
SECOND	11.2	0
TOTAL	16.0	
BOTH STAGE RETURN*		
FIRST	4.8	4.8
SECOND	10.4	3.0
TOTAL	15.2	

*SECOND STAGE RETURNS TO SHUTTLE-COMPATIBLE ORBIT

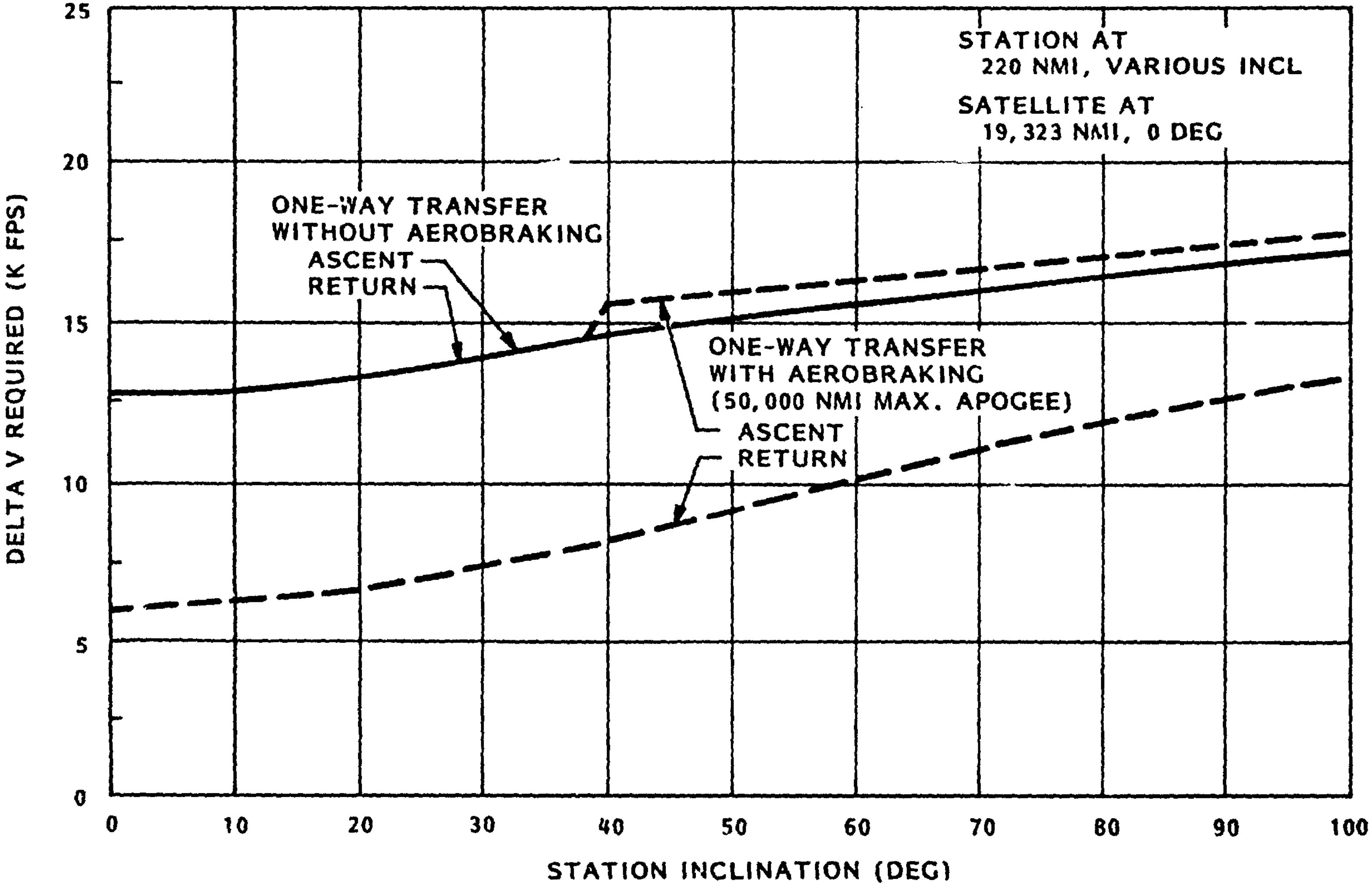
Lockheed

DELTA V FOR IMPULSIVE TRANSFER TO 0-DEG. GEO SATELLITE

One potential servicing mission for a space-station-based OTV is one-way support of GEO satellites. First, we will consider GEO satellites at 0-deg. inclination. Since there is no nodal drift between the station and a 0-deg. inclination satellite, a two-dimensional plot of required delta V versus station inclination is adequate to define the effect of station inclination on transfer energy. Time (days wait before ascent) is not a factor in this instance. As shown on the facing page, the minimum energy transfer is made with a three-burn trajectory but without aerobraking. Since the terminal altitude is so high (19,323-nmi) an aerobraking trajectory (with a constrained maximum apogee of 50,000-nmi) on the ascent maneuver is of no benefit. Aerobraking will reduce the energy required on the return trajectory.

As shown in the graph, there is an effect of station location on the delta V required the transfer to GEO. However, the basic energy requirement is close to 15,000 ft/sec., which is similar to the energy required to reach an LEO satellite at non-optimum times. Transfers at this level are clearly within the capability of existing spacecraft such as the Centaur or the IUS. The propellant required to make the transfer or, conversely, the payload limitations of existing OTVs, can be determined from the data on pages OP-15 and OP-16.

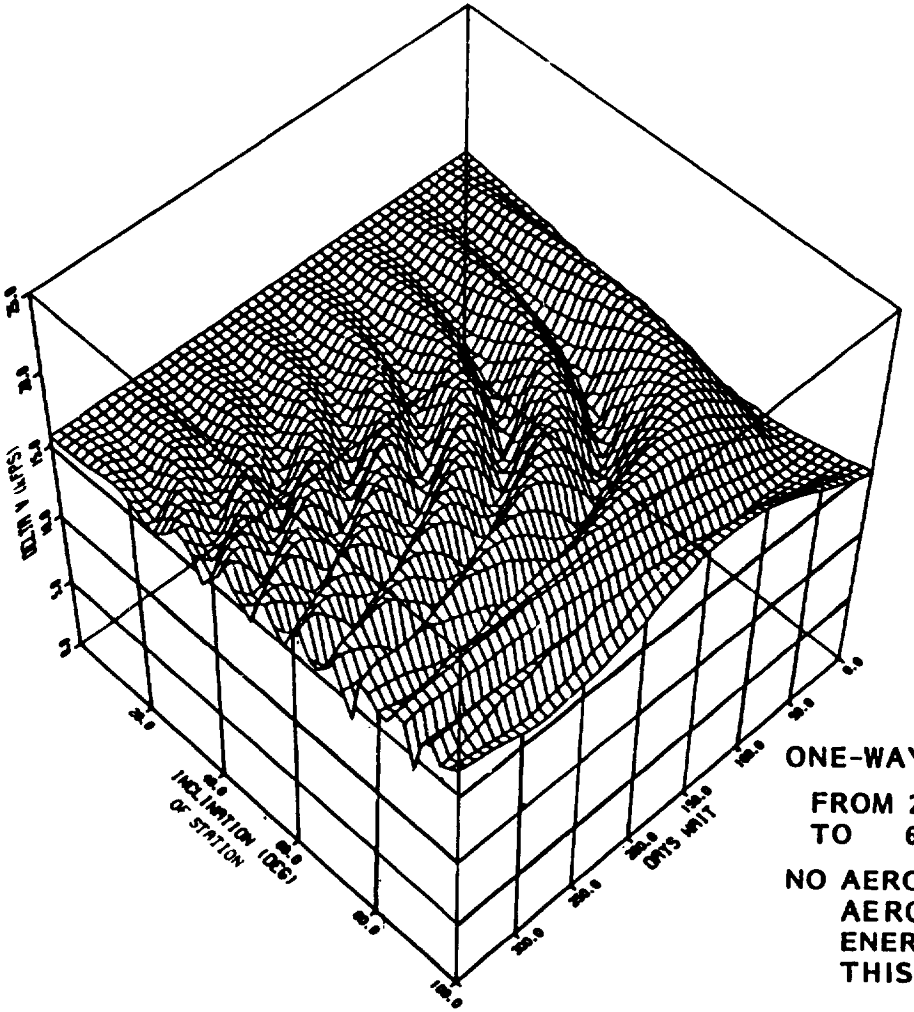
DELTA V FOR TRANSFER TO 0 DEG GEOSYNCHRONOUS EARTH ORBIT SATELLITE



TRANSFER TO 65-DEG. GEO FROM VARIOUS STATION INCLINATIONS

There is relative nodal drift between the GEO satellite at 65-deg. and the space station at 220-nmi. Thus, a three-dimensional representation is again the easiest way to examine the influence of space station inclination on energy required to transfer to GEO. As in the preceding case, aerobraking maneuvers on ascent from LEO to 19,323-nmi actually increase the energy required. Aerobraking on reentry would save energy since the terminal altitude is in LEO. As shown in the figure, a variation in delta V is required as a function of time, but the entire surface is bounded by a maximum energy from 15,000 ft/sec. to 17,000 ft/sec.

TRANSFER TO A 65 DEG GEO SATELLITE FROM VARIOUS STATION INCLINATIONS



ONE-WAY (ASCENT) TRANSFER

FROM 220 NMI
TO 65 DEG ORBIT AT 19,323 NMI

NO AEROBRAKING (USE OF AEROBRAKING INCREASES ENERGY REQUIRED FOR THIS SET OF PARAMETERS)

CONCLUSIONS
CONSTRAINTS ON SPACE OPERATIONS DUE TO ORBITAL MECHANICS

The space station is clearly suitable as a base for space operations, possibly one of the most important functions of a station. For a specific mission, space-station-based and Shuttle-based support should be compared. As shown on the facing page, the station is the better choice for a broad class of satellites. The station offers a unique capability for support to any LEO orbit, but the energy required is substantial even for one-way missions. Thus, station-based missions in this category should be restricted to critical activities that warrant the energy expenditure. Several significant missions meet these criteria. In fact, these missions are so important that they are a key element in providing justification to proceed with the initial phase of the space station.

SPACE STATION PROGRAMS

CONCLUSIONS

SPACE STATION PROVIDES POWERFUL CAPABILITY FOR SPACE-BASED OPERATIONS

UNDERSTANDING OF ORBITAL MECHANICS CONSTRAINTS IS ESSENTIAL FOR PROPER MISSION PLANNING

STATION IS BETTER THAN SHUTTLE FOR SUPPORTING SCHEDULED SERVICING, MAINTENANCE, AND RESUPPLY OF:

- PAYLOADS AND SATELLITES IN STATION TRACKING ORBITS
- SATELLITES IN NEARBY INCLINATIONS AT NODAL COINCIDENCE; TO SERVICE MAJORITY OF SATELLITES, REQUIRE STATIONS AT 28.5°, 60°, 90°
- GEO SATELLITES (STATION LOCATION NOT STRONG DRIVER)

SHUTTLE IS PROBABLY BETTER THAN STATION FOR:

- SERVICING SATELLITES AT NON-OPTIMUM TIMES
- EMERGENCY RESUPPLY

STATION OFFERS UNIQUE CAPABILITY INDEPENDENT OF STATION OR SATELLITE LOCATION FOR:

- RECONSTITUTION VIA SPACE-BASED LAUNCH
- SHUTTLE CREW RESCUE

Lockheed

SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

1.1 USER ALIGNMENT PLAN
1.2 SCIENCE AND APPLICATIONS
- PHYSICAL SCIENCES
- LIFE SCIENCES

1.3 COMMERCIAL
1.4 U.S. NATIONAL SECURITY
1.5 SPACE OPERATIONS
1.6 REQUIREMENTS FROM USER NEEDS
1.7 FOREIGN CONTACTS

Lockheed

PRECEDING PAGE BLANK NOT FILMED

WHY VISIT FOREIGN CONTACTS

The tremendous cost of a space station relative to any single country's financial capability necessitates a cooperative effort. Furthermore, the awakening of third nation space consciousness and their proprietary views of space also call for cooperation and sharing of space station results.

In December 1982, we visited a number of European companies engaged in space work:

Lockheed

SPACE STATION PROGRAMS

WHY VISIT FOREIGN CONTACTS

- PART OF CONTRACT REQUIREMENTS
- EUROPEANS AND JAPANESE VERY ACTIVE IN SPACE EFFORT
- MANY THIRD NATIONS ALSO HAVE SHOWN INTEREST IN SPACE
- IMPROVE INTEREST AND INVESTMENT BASE OF SPACE STATION SYSTEM

Lockheed

FOREIGN INFORMATION EXCHANGE

Four foreign companies signed agreements. SPAR of Toronto sent an engineer to work with us on the space station for 2 weeks. With the Europeans we have an information exchange agreement, dependent upon State Department approval.

The European visit covered a broad range of companies, research institutes and government facilities. All of these have been involved in space exploration for some time; and they presently are engaged in numerous space research/flight projects.

SPACE STATION PROGRAMS

FOREIGN INFORMATION EXCHANGE

AGREEMENTS AT NO COST WERE FORMALIZED WITH:

SPAR	-	TORONTO, CANADA
GTS	-	LONDON, ENGLAND
MBB/ERNO	-	BREMEN - GERMANY
DORNIER	-	FRIEDRICHSHAFEN - GERMANY

VISITS MADE 6 TO 23 DECEMBER 82:

ESA	-	PARIS
ONERA	-	PARIS
MAX PLANCK INSTITUTE	-	MUNCHEN
MBB/ERNO	-	MUNCHEN AND BREMEN
DORNIER	-	FRIEDRICHSHAFEN
ERNO	-	BREMEN
DFVLR	-	KOLN
FOKKER	-	SCHIPHOL
GTS	-	LONDON
TNO	-	DELFT
ESTEC	-	NOORDWYK

Lockheed

FOREIGN VISIT FINDINGS

Throughout these visits the Europeans had a unanimously enthusiastic behavior towards the prospects of a space station. However, without exception they stated a desire to be more involved than just as nuts and bolts manufacturers. They feel that being given the responsibility for a total space station subsystem would be more in line with their technical capability.

FOREIGN VISIT FINDINGS

- EUROPEANS ENTHUSIASTIC ABOUT SPACE STATION
- FINDINGS OF ESA STUDY ABOUT SAME AS LOCKHEED STUDY
- EUROPEANS WANT RESPONSIBILITY FOR TOTAL S.S. SUBSYSTEM
- CAPABLE AND WILLING TO BUILD ANY PART OF SPACE STATION

RECOMMENDATIONS FOR FOREIGN COOPERATIVES

The majority of contacts would like to have more responsibility. For instance, the responsibility for a total subsystem should be given to one or a group of countries. This will give the small member countries a chance to participate in space exploration with a space station.

Maybe America should look into a real cooperative partnership with the Europeans, Japanese, and others in space station development.

This type of project would lend itself very well to a partnership or venture approach. Realizing the problems that NASA would have with this type of arrangement, it is suggested that a commercial group/company be installed between NASA and the venture member countries.

SPACE STATION PROGRAMS

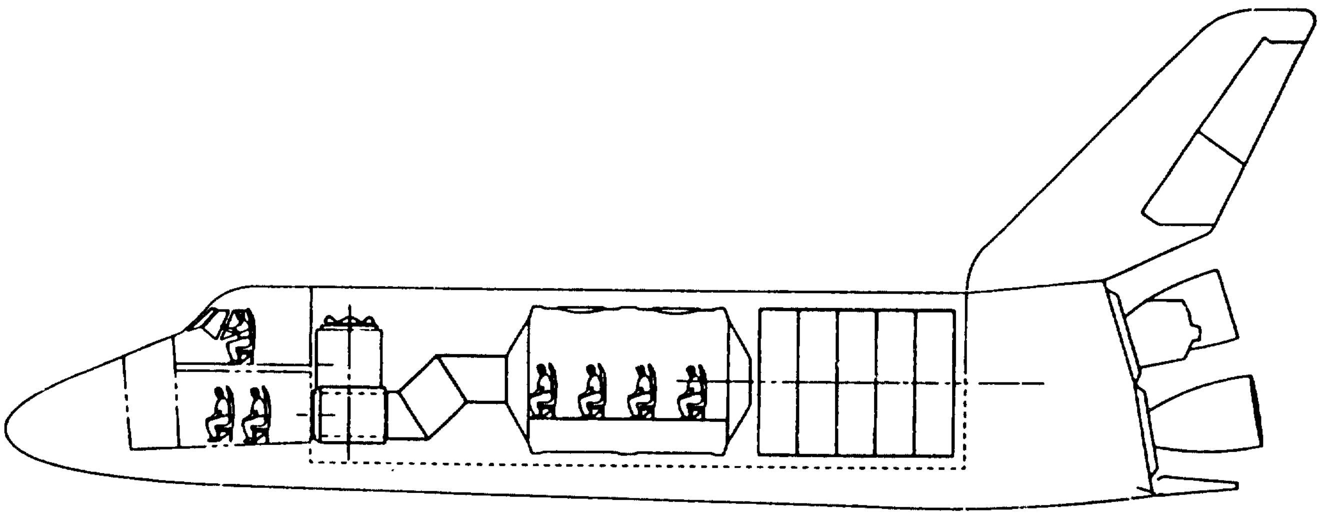
RECOMMENDATIONS FOR FOREIGN COOPERATIVES

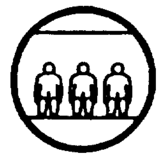
- CREATE TRULY INTERNATIONAL SPACE STATION
- VENTURE COUNTRIES WITH SPECIFIC TALENTS
- EACH COUNTRY RESPONSIBLE FOR A COMPLETE PART OR SUBSYSTEM
- INTEGRATION AND LAUNCH PERFORMED BY AMERICAN PARTNER
- SPACE STATION COULD BE BUILD AT AN EARLIER DATE
- FINANCIAL BURDEN LESS FOR U.S.A.

RE-SUPPLY AND CREW ROTATION

With the number of personnel on a space station increasing as missions become more complex and demanding, a need arises for a personnel transportation vehicle. On the next page is shown a modification of the space lab module which now can carry 12 people. With four more people in the shuttle, it allows transport of 16 people. Required modifications to the space lab module will be substantial: all racks removed, floors strengthened, and ECLSS upgraded, just to name a few. The expendable supplies for a 16 man crew for 6 months weigh 27,000 lbs and occupy 2400 cu ft. Both the crew and expendable supplies can be carried in a single shuttle launch, if the Spacelab axis tunnel is shortened as shown. However, this would be a specific non strategic subsystem to the overall space station system, responsibility for which could be given to the space lab manufacturers (Germany).

RE-SUPPLY AND CREW ROTATION



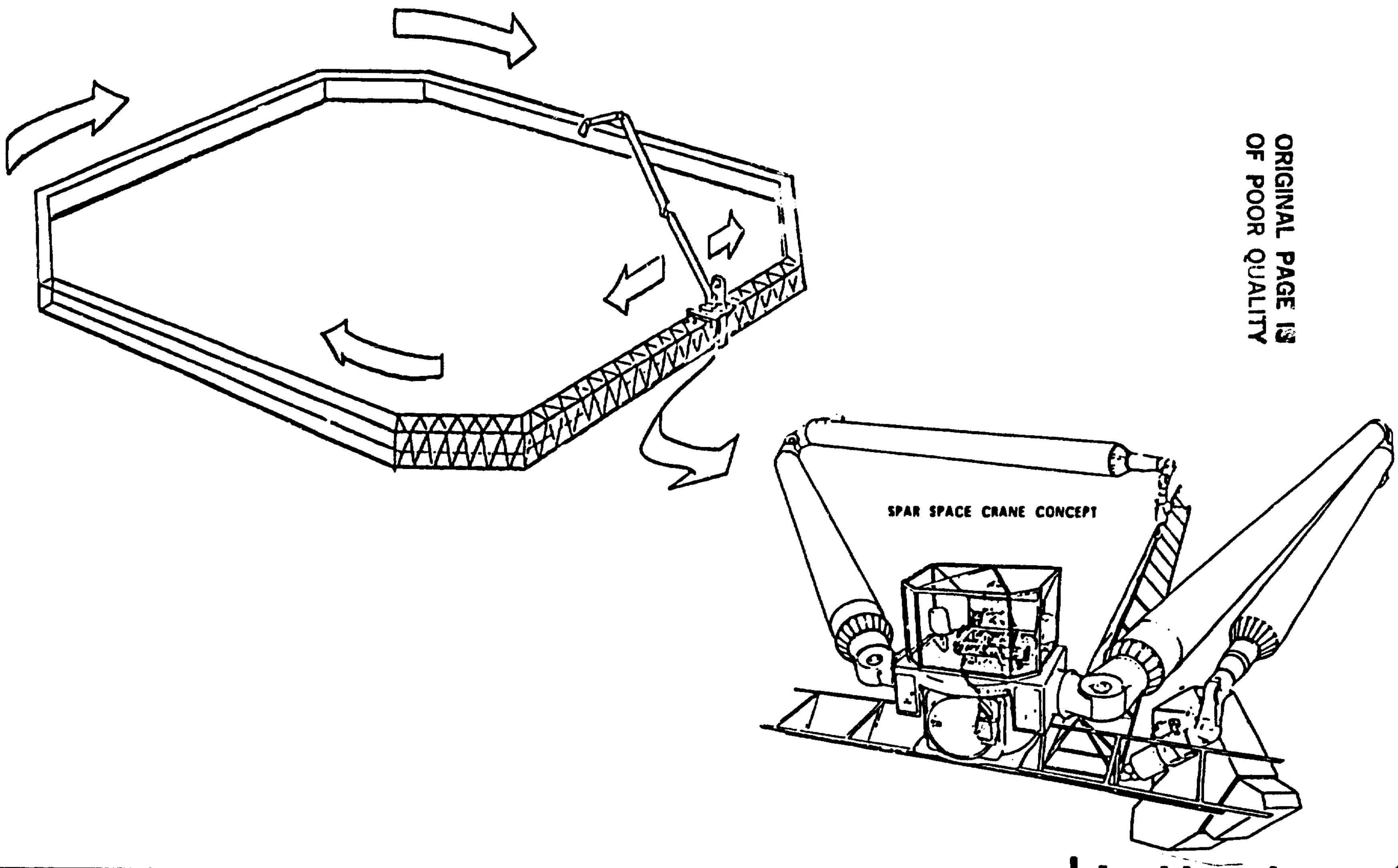


ORIGINAL PAGE IS
OF POOR QUALITY

TRACKED - CRANE WITH CAB

The concept shown here exemplifies how a foreign country could participate in the space station program. In this instance, Spar Corporation of Canada would design and develop advanced versions of the remote manipulator system. Such isolatable sub-system components can be integrated as single items requiring only basic interface controls to ensure compatibility with station requirements. Other payload handling and special purpose equipment readily can be detached from the main space staton stream and also be developed in Canada.

TRACKED-CRANE WITH CAB



SPACE STATION PROGRAMS

TASK 1—MISSION REQUIREMENTS

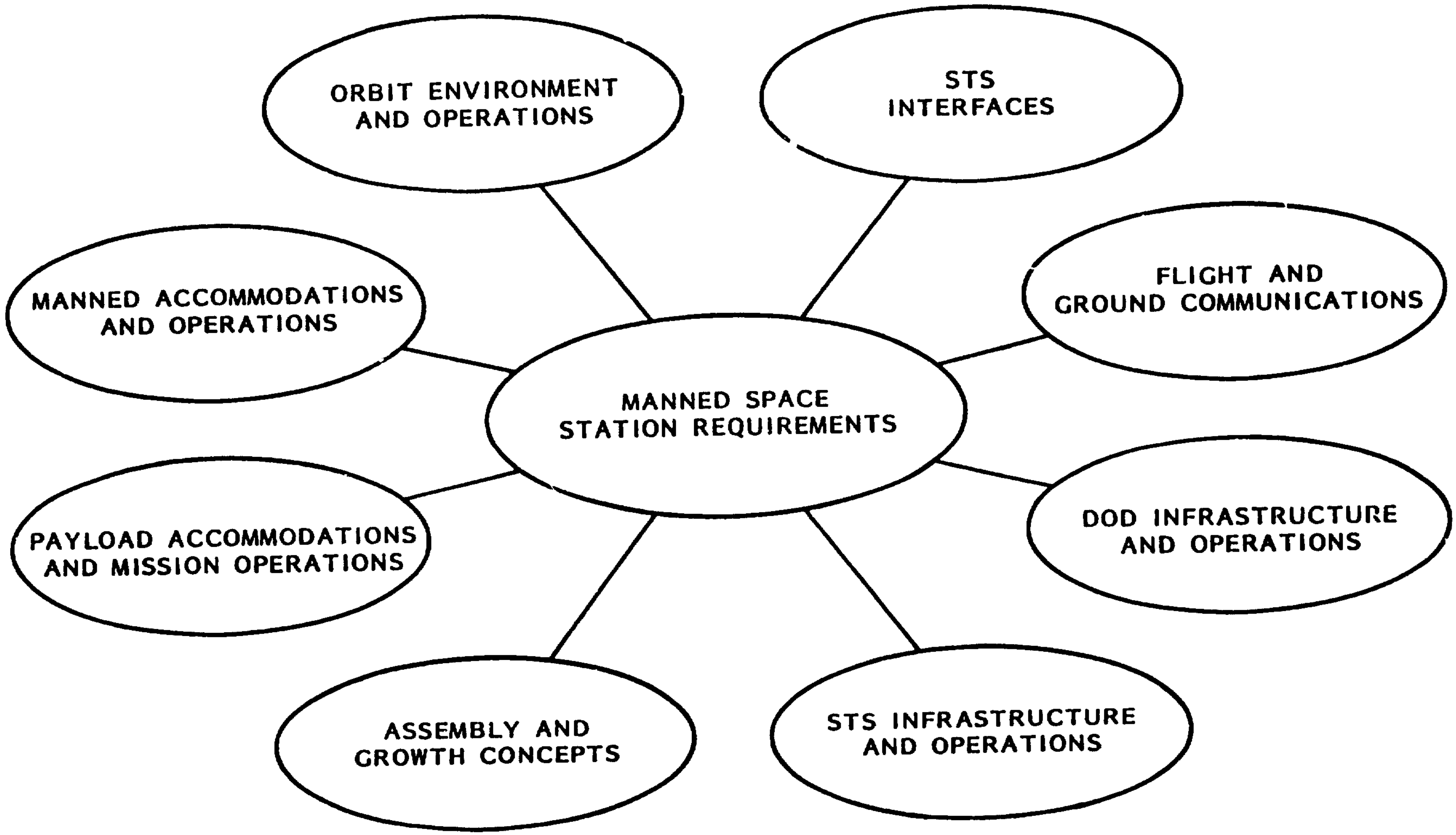
1.1 USER ALIGNMENT PLAN
1.2 SCIENCE AND APPLICATIONS
  — PHYSICAL SCIENCES
  — LIFE SCIENCES
1.3 COMMERCIAL
1.4 U.S. NATIONAL SECURITY
1.5 SPACE OPERATIONS
1.6 REQUIREMENTS FROM USER NEEDS
1.7 FOREIGN CONTACTS

Lockheed

REQUIREMENTS SOURCES

The primary source of Space Station of requirements is the user needs. Requirements are also imposed by the nature of operations to be conducted and by the infrastructure elements with which the station must interface. The chart on the right illustrates source categories of requirements. These categories cover both the requirements that are imposed on the station itself, and those that result from interfaces with the STS elements flight and ground communications, etc.

REQUIREMENTS SOURCES



MANNED SPACE STATION FUNCTIONS

Our user contacts resulted in a set of functions that must be accomplished by a manned space station either on the station itself or on a station controlled platform/free flyer. It is the functions that must be performed that determine requirements. The adjacent chart lists those broad categories of functions that lead to requirements.

SPACE STATION PROGRAMS

MANNED SPACE STATION FUNCTIONS

- SUPPORT FOR LONG DURATION PAYLOADS THAT NEED DIRECT MANNED INTERVENTION
- SUPPORT MANNED SPACECRAFT THAT NEED PERIODIC MANNED INTERVENTION (ASSEMBLY, EXPERIMENT CHANGEOUT)
- ORBIT PLACEMENT AND RECOVERY OF PAYLOADS
- SUPPORT ORBIT STAGING, LAUNCH AND RECOVERY OF FREE FLYERS
- TEST BED FOR DEVELOPMENT OF SENSORS, TECHNIQUES, SUPPORT SYSTEMS
- LOGISTICS SUPPORT INTERFACE WITH STS

MISSION SUPPORT REQUIREMENTS

Each Space Station mission scenario was analyzed to determine requirements that might be readily accomplished on the Space Station. From these requirements were developed the Mission Support Requirements, i.e., the capability the space station would need to provide in order to successfully fulfill the mission requirements. In many cases these support requirements have been included in the scenarios contained in Attachment 2, Volume 1.

This series of 14 charts list the principal drivers that will influence space station architecture - crew size, power requirements, support, environment, EVA and manned interaction as well as orbit parameters. Based on these drivers and needs identified by users, generic types of space stations were established for each of the missions (scenarios). These ranged from manned modules to attached laboratories and platforms, both attached and free flying. These broadly identified requirements were an input to Task 2, Mission Implementation Concepts in which space station architectural concepts were developed.

SPACE STATION PROGRAMS

MISSION SUPPORT REQUIREMENTS - SCIENCE

SS SUPPORT CAPABILITY \ MISSION	LIFE SCIENCES HUMAN RESEARCH LABORATORY	LIFE SCIENCES NON-HUMAN RESEARCH LABORATORY	CELESTIAL OBSERVATORY	SPACE ENVIRONMENT FACILITY
SENSER PLATFORM ATTACHED	ATTACHED SHIRTSLEEVE LAB MODULE	ATTACHED LAB MODULE W/ PLANT/ANIMAL VIVARIA	ATTACHED PALLET. REMOTE MONITOR	ATTACHED PALLETS. REMOTE MONITOR
TETHER OR FREE FLYER			POSSIBLE	POSSIBLE
LIFETIME	10 YEARS	10 YEARS	10 YEARS	10 YEARS
ORBIT	28.5° 300 KM	28.5° 300 KM	28.5° 300 - 400 KM	57° 400 KM
POINTING	N/A	N/A	SOLAR. IPS SLEW RATE 180° -5 MIN.	SOLAR. EARTH LIMB. RADAR & MAGNETIC FIELD POINTING
POWER	4 KW	8 KW	1.4 KW (AVE)	10KW

Lockheed

SPACE STATION PROGRAMS

MISSION SUPPORT REQUIREMENTS - SCIENCE (CONTINUED)

SS SUPPORT CAPABILITY / MISSION	LIFE SCIENCES HUMAN RESEARCH LABORATORY	LIFE SCIENCES NON-HUMAN RESEARCH LABORATORY	CELESTIAL OBSERVATORY	SPACE ENVIRONMENT FACILITY
LOGISTICS SUPPORT	90 DAY LAB SUPPLIES AND CONSUMABLES	90 -180 DAYS LAB SUPPLIES AND CONSUMABLES		
REFUELING	N/A	N/A	N/A	N/A
ORBIT ASSEMBLY	INTACT DELIVERY	INTACT DELIVERY	INTACT DELIVERY	SENSOR ADDITION/ RETRIEVAL
CHECKOUT	N/A	N/A		YES
CREW SIZE	2 EXPERIMENTERS 4 CREW MEN SUBJ	2 EXPERIMENTERS	2 EXPERIMENTERS	2 EXPERIMENTERS
EVA	N/A	N/A	PERIODIC	PERIODIC
LOW G ENVIRONMENT	YES - FOR PERIODIC TEST	N/A	N/A	N/A

Lockheed

SPACE STATION PROGRAMS

TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

MISSION IMPLEMENTATION CONCEPTS AND OBJECTIVES

The objectives of this part of the study are to define space station system concepts in terms of functional architecture and configuration that will accommodate the projected mission requirements for the 1990 to 2000 era, and to define evolutionary steps to implement the system.

The terminology used throughout this part of the study is as follows:

- Space station - a manned assembly in low earth orbit (LEO)
- Space station system - space station element and other operating payload, experiment, and support elements
- Experiment - a collection of hardware designed to achieve a single investigative objective
- Payload - a grouping of multiple experiments designed to achieve a major objective, either single purpose or multipurpose
- Configuration - a pictorial structural arrangement of major hardware that depicts a space station
- Attached payload or experiment - physically attached to space station
- Detached payload or experiment - physically separated from space station; may be in orbit alone or tethered to space station
- Free flyer - a vehicle in orbit alone, may have single or multiple payloads or experiments
- Satellite or spacecraft - a single mission vehicle in orbit alone
- Platform - an unmanned assembly in separate orbit
- Support elements - major interfacing operational elements of the total space infrastructure consisting of the space communication satellites (TDRSS, MILSATCOM); ground-based tracking, communications, and control; and the Space Transportation System (STS) launch base and Shuttle vehicle
- Orbit transporters/services - teleoperator maneuvering system (TMS) and orbit transfer vehicle (OTV)

SPACE STATION PROGRAMS

MISSION IMPLEMENTATION CONCEPTS OBJECTIVES

TO IMPLEMENT MISSION REQUIREMENTS FOR 1900 - 2000 ERA

- DEFINE AND ANALYZE A RANGE OF ALTERNATIVE SYSTEM CONCEPTS TO MEET MISSION AND SATISFY OPERATIONAL REQTS.
- DEVELOP AND ANALYZE ARCHITECTURAL OPTIONS
- DEFINE A PLAN FOR EVOLUTION OF SPACE STATION

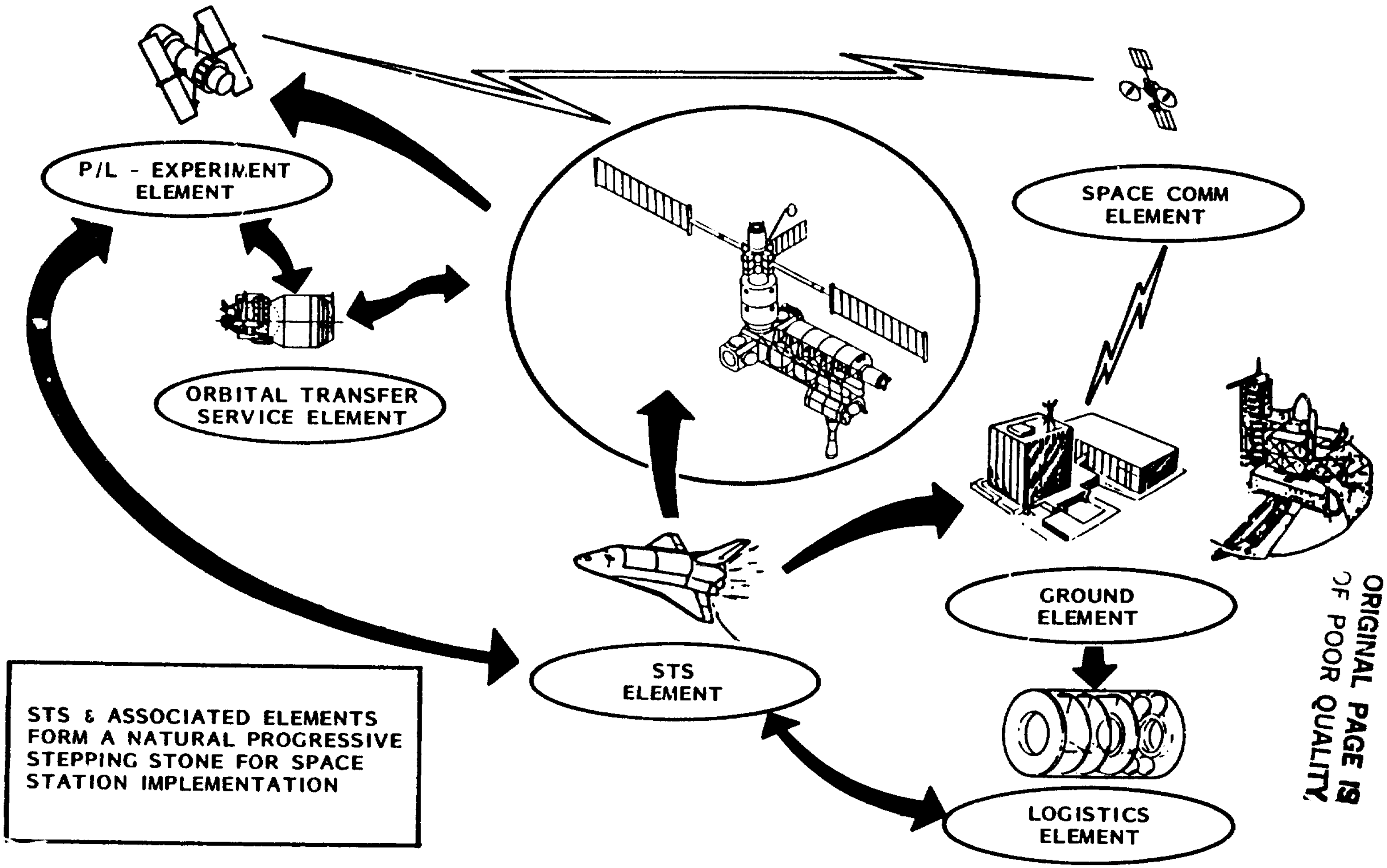
SPACE STATION SYSTEM INFRASTRUCTURE AND TOTAL SYSTEM ARCHITECTURE

An abbreviated overview of the basic station infrastructure is illustrated on the facing page. This architectural overview does not include classified U.S. national security elements; however, the infrastructure is highly applicable at the element level. A strong case is made for the natural and progressive evolution of the station using the basic Space Transportation System (STS) as the stepping stone to achieve a smooth transition and cost-effective implementation.

An important element of the infrastructure, which to date appears to have received less emphasis but is highly important, is the integrated logistics support (ILS) element of the overall station infrastructure. Both nominal and emergency ILS factors must be considered very early in the station concept development sequence as they can substantially affect the basic station and support element architecture. Pivotal also is the inherent need for an orbital transport system capability that is key to servicing and spacecraft positioning scenarios and associated mission needs. Communication is also an extremely important element and the basic issue of station autonomy versus ground support will be a key trade study and system and subsystem architectural impact and driver.

SPACE STATION PROGRAMS

SPACE STATION SYSTEMS INFRASTRUCTURE & TOTAL SYSTEMS ARCHITECTURE



STS & ASSOCIATED ELEMENTS FORM A NATURAL PROGRESSIVE STEPPING STONE FOR SPACE STATION IMPLEMENTATION

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

SPACE STATION PROGRAMS

TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

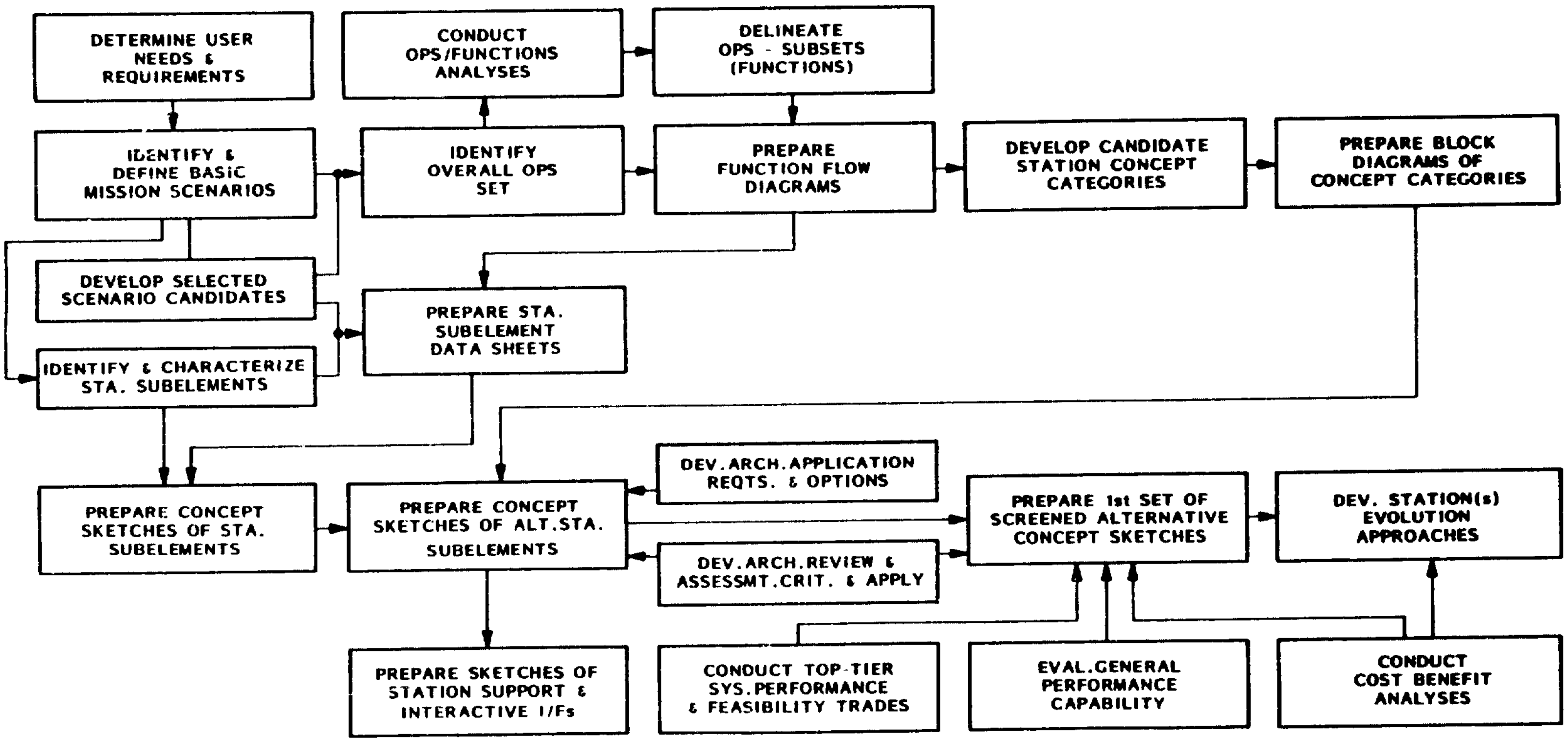
APPROACH TO DEFINING MISSION IMPLEMENTATION CONCEPTS

The basic approach to the station architectural development study effort is portrayed on the facing page. Certainly, the effort was substantially influenced by the user needs and requirements developed in Task 1 of this study. Significant effort in Task 1 was also given to development of the set of mission scenarios that formed the basis of the operation/function analyses then conducted. A number of scenario operation/function flow diagrams were prepared from which a basic set of architectural concept definitions were developed. Data sheets indicating station subelement characteristics were then generated which, in concert with the aforementioned information provided by the basic data base, were used in the architectural development activity.

A wide range of architectural station concepts were prepared and evaluated as to potential practicality, feasibility, mission suitability, cost, and support potential. Simultaneously, top-tier requirements and general assumptions were then prepared for subsequent design activity. Also concurrently, basic station support functions and interface needs were delineated for operational criteria input. Architectural review and assessment criteria were prepared for use in subsequent examination of the proposed set of station alternative concept approaches. Initial sketches of the cadre of station candidate concepts were prepared and screened according to previously prepared criteria. Again, top-tier requirements were imposed and several performance and feasibility trades conducted. Rationale for station evolution was defined and applied to the more promising candidate station concepts. Concurrently, costing analyses were conducted relative to the more viable station concept(s) to further substantiate the evolutionary approach and to support the reference initial and full-up station concept configuration.

SPACE STATION PROGRAMS

APPROACH TO DEFINING MISSION IMPLEMENTATION CONCEPTS



Lockheed

SCENARIO 11--OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY--MISSION FUNCTIONAL SEQUENCE

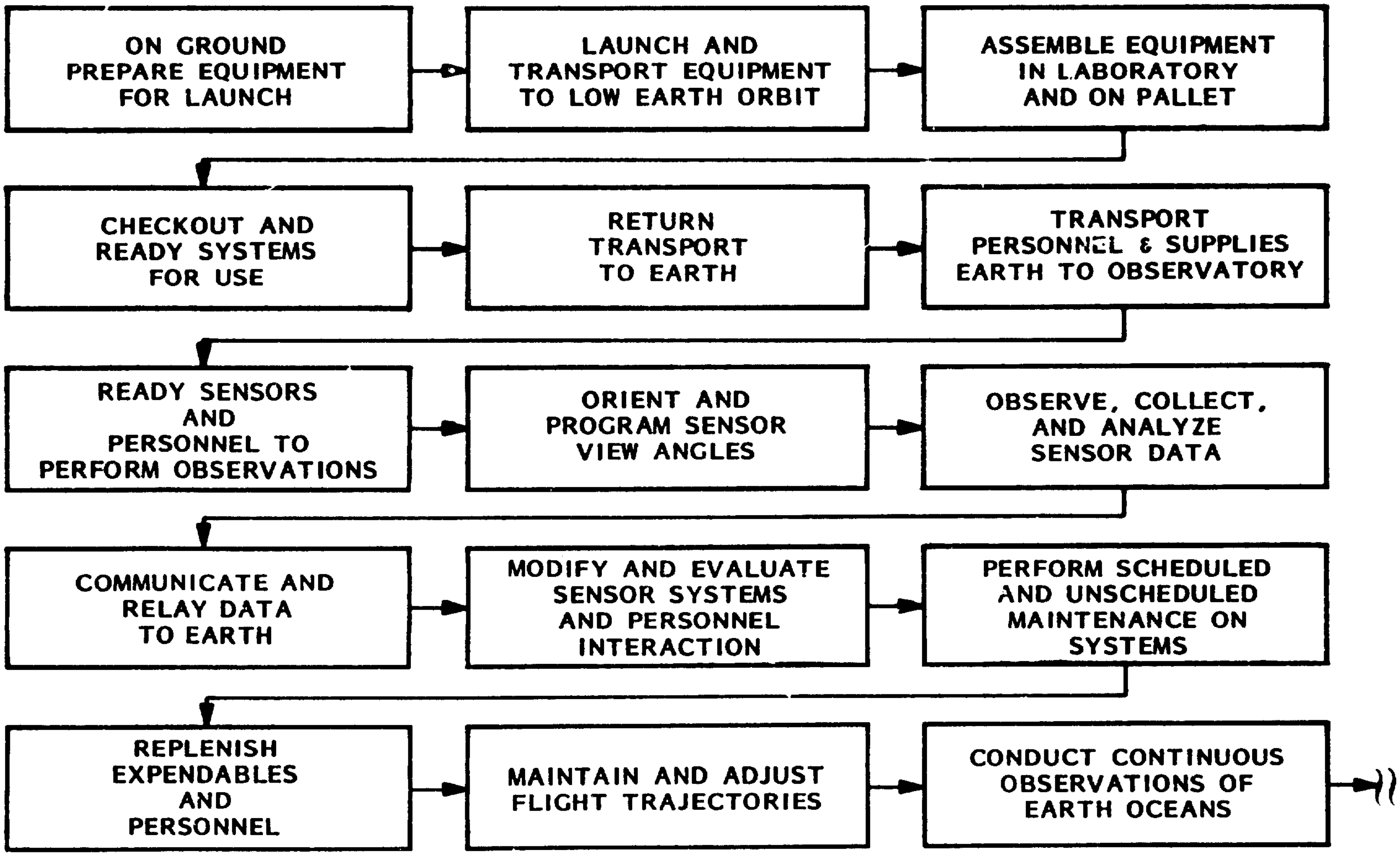
The objective of this mission is to provide a development laboratory and testbed in space where sensor instruments, systems, and operating procedures intended for use in ocean surveillance can be developed and evaluated. By means of direct crew scientist hands-on interaction with breadboard and development equipment, the operational characteristics and man's role in controlling sensor targeting and interpreting sensor data can be evaluated.

The functional sequence to position and operate an oceanography observatory development laboratory in LEO is shown here.

SPACE STATION PROGRAMS

SCENARIO 11

OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY MISSION FUNCTIONAL SEQUENCE



SCENARIO 11--OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY ARCHITECTURAL CONCEPT

The system architecture for the oceanography observatory development laboratory is shown here. An enclosed laboratory-type module in combination with an open-faced experiment pallet is directly coupled to the basic space station subelements. This permits personnel to perform hands-on interaction with experiments in the laboratory and remote interaction with experiments on the pallet. The STS provides direct support to initially transport the laboratory module, pallets, and experiments to LEO and to continue logistics support for consumables, crew scientist rotation, and experiment modifications during mission lifetime. Data evaluation is conducted onboard the space station, and data are transmitted to the ground data systems via the space station to ground communication link.

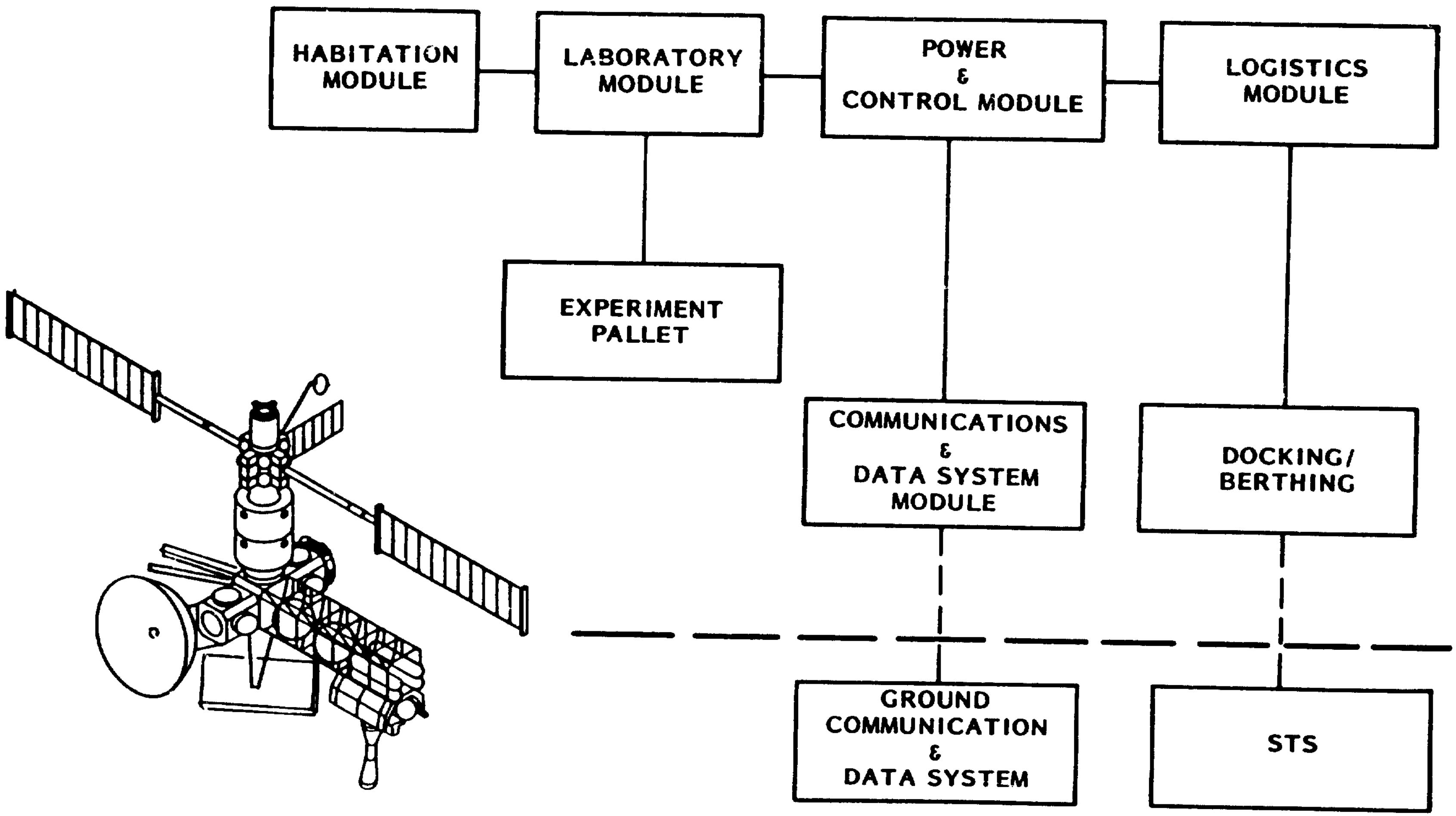
Functions of the system architecture are presented below:

	Module	Functions
1.	Habitation	Living and maintenance of crew
2.	Laboratory	Hands-on experiment, sensor setup and operations
3.	Experiment pallet	Remote experiment, sensor testbed
4.	Power and control	Electrical power, attitude stabilization, and control
5.	Communication and data system	Voice and data link, data evaluation, and display
6.	Docking/berthing	Docking/berthing for Shuttle; transfer personnel, equipment, and supplies
7.	Logistics	Storage for facility and payload supplies
8.	Ground communication and data	Tracking, voice/data communication, and data distribution
9.	STS	Shuttle ground to space transport, resupply logistics

SPACE STATION PROGRAMS

OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY ARCHITECTURAL CONCEPT

SCENARIO 11



Lockheed

SCENARIO 11--ROLE OF SPACE STATION TO SUPPORT OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY

The space station provides direct, continuous, long-term support to the oceanography observatory development laboratory mission. The station provides online direct electrical power and environmental interfaces and supports onboard data analysis and conferencing communications and data transfer to the ground. Direct EVA-type support is provided to service and maintain experiments mounted on the open pallet. Laboratory equipment maintenance and service and consumable replenishment are conducted continuously.

Space station attributes to support this mission are shown here.

ROLE OF SPACE STATION TO SUPPORT OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY

SCENARIO 11

ATTRIBUTES

- PROVIDE LONG-DURATION HABITATION FOR PERSONNEL
- PROVIDE SHIRTSLEEVE INTERACTIVE "HANDS ON" LABORATORY
- PROVIDE REMOTE INSTRUMENTATION/SENSOR TESTBED
- PROVIDE ELECTRICAL POWER AND DATA/COMMUNICATIONS INTERFACE
- PROVIDE VOICE AND DATA LINK TO GROUND
- PROVIDE ALTITUDE AND ATTITUDE ORIENTATION
- PROVIDE PERIODIC REPLENISHMENT OF EXPENDABLES AND PERSONNEL
- PROVIDE SCHEDULED AND UNSCHEDULED MAINTENANCE
- PROVIDE DOCKING AND OPERATIONAL INTERFACE WITH STS

SUMMARY OF SPACE STATION ATTRIBUTES TO SUPPORT MISSION SCENARIOS

Space station attributes to support the spectrum of missions analyzed previously are given in this chart. Most significantly, the greater number of attributes (functional capabilities) are required to support the category of space operations type mission such as servicing satellites in co-orbiting and other LEO positions and performing satellite structural assembly in LEO.

SPACE STATION PROGRAMS

SUMMARY OF SPACE STATION ATTRIBUTES TO SUPPORT MISSION SCENARIOS

ATTRIBUTES \ MISSIONS	BASIC SPACE STATION	HUMAN LIFE SCI. RESEARCH LAB	NON-HUMAN LIFE SCI RESEARCH LAB.	CELESTIAL OBSERVATORY LABORATORY	SPACE ENVIROMENT FACILITY	EARTH OBSERVATION FACILITY	GLOBAL HABITABILITY OBSERVATORY LAB	METEOROLOGICAL FACILITY	MATERIAL PROCESSING RESEARCH LABORATORY	MATERIAL PROCESSING OPERATIONS FACILITY	SPACE OBSERVATION DEVELOPMENT LAB	OCEANOGRAPHY OBS. DEVELOPMENT LAB	ORBITING NATIONAL COMMAND POST	SPACE OBJECTS IDENTIFICATION SYSTEM	SATELLITE SERVICING LEO	LARGE SATELLITE STRUCTURE ASSEMBLY
• CREW, OPERATORS HABITATION	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
• POWER, ALTITUDE, ATTITUDE CONTROL	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
• OPEPATOR HANDS ON EXPERIMENT INTERACTION		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
• OPERATOR ATTACHED EXP. REMOTE INTERACTION					✓	✓	✓				✓	✓		✓		
• OPERATOR DETACHED EXP. REMOTE INTERACTION				✓				✓		✓						
• PAYLOAD HANDLING ASSEMBLY, CHECKOUT		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
• COMMUNICATIONS & DATA HANDLING	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
• TRANSPORT PERSONNEL & SUPPLIES	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
• SHUTTLE DOCKING AND LOGISTICS	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
• MAINTAIN & SERVICE ATTACHED PAYLOADS/EXPMTS		✓	✓		✓		✓		✓		✓	✓		✓		
• MAINTAIN & SERVICE DETACHED PAYLOADS/EXPMTS				✓				✓		✓						
• MAINTAIN & SERVICE CO-ORBITING SATELLITES															✓	
• MAINTAIN & LAUNCH/RECOVER TRANSPORT STAGES				✓				✓		✓			✓		✓	
• ASSEMBLE, CHECKOUT, INTEGRATE SATELLITES				✓				✓		✓					✓	✓
• CRYOGEN STORAGE & RESUPPLY															✓	
• PROPELLANT/GAS STORAGE & RESUPPLY															✓	✓
• ASSEMBLE, ERECT, TRANPORT LARGE STRUCTURES																✓
• MAINTAIN AND SERVICE ATTACHED EQUIPMENTS		✓	✓						✓							

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

SPACE STATION PROGRAMS

TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

ALTERNATIVE SPACE STATION SYSTEM CONCEPTS TO IMPLEMENT MISSION SCENARIOS

From the data tabulated in the previous chart and mission requirements data developed in Task 1, a compatibility analysis was performed to define alternative system concepts to implement the 15 mission scenarios.

Missions were grouped on the basis of commonality of orbit characteristics, functional requirements, and unique national security needs. Analysis results indicate that no single space station concept can satisfy all missions. Five system concepts were selected to implement the mission grouping as shown in this chart.

- Concept A is a basic space station with attached enclosed laboratory configuration in a 57-deg inclination orbit and will accommodate those missions to perform space environment, ground, and ocean Earth observation.
- Concept B is a basic space station with attached enclosed laboratory configuration in a 28.5 deg inclination orbit and will accommodate those missions to perform life science and materials processing investigations.
- Concept C is a basic space station supporting detached free-flyer satellites in a 28.5-deg inclination orbit and will accommodate automated observation facilities for celestial and meteorological investigations and a man-tended automated materials production facility.
- Concept D is a basic space station with attached facilities for performing maintenance and servicing of satellites and structural assembly and launch on orbit of large structure satellites.
- Concept E are space station supported unique applications for U.S. national security and will include an attached enclosed laboratory for space objects identification and a detached autonomous orbiting command post.

SPACE STATION PROGRAMS

ALTERNATIVE SPACE STATION SYSTEM CONCEPTS TO IMPLEMENT MISSION SCENARIOS

CONCEPT A

ATTACHED LABORATORY

57° INCLINATION

No.

11 - OCEAN OBSERVATORY LABORATORY

6 - GLOBAL HABITABILITY LABORATORY

4 - SPACE ENVIRONMENT FACILITY

5 - EARTH OBSERVATION FACILITY

CONCEPT B

ATTACHED LABORATORY

28.5° INCLINATION

No.

10 - SPACE OBSERVATION LAB

8 - MAT'L PROCESSING LAB

2 - NON-HUMAN RESEARCH LAB

1 - HUMAN RESEARCH LAB

CONCEPT C

DETACHED FACILITIES

28.5° INCLINATION

No.

3 - CELESTIAL OBSERVATORY

9 - MAT'L PROCESSING FACILITY

7 - METEOROLOGICAL FACILITY

CONCEPT D

SPACE-BASED SERVICING

AND STRUCTURAL ASSEMBLY

LEO - 28.5° INCL.

No.

14 - SATELLITE SERVICING

15 - STRUCTURAL ASSEMBLY

CONCEPT E

U.S. NATIONAL SECURITY

28.5° INCLINATION

No.

12 - ORBITING COMMAND POST

13 - SPACE OBJECTS IDENTIFICATION

Lockheed

ALTERNATIVE CONCEPTS - SYSTEM ELEMENT INTERFACES AND FEATURES
CONCEPT A - ATTACHED LABORATORY - 57-deg ORBIT

Based on the five alternative systems concepts shown in the previous chart, the major system element interfaces and features were defined. The following series of charts tabulates these major element interfaces and features to implement the 15 mission scenarios. These data are used in subsequent analyses to define, evaluate, and select configurations for the space station system.

Element interfaces and features for alternative space station Concept A are shown in this chart.

ALTERNATIVE CONCEPTS — ELEMENT INTERFACE AND FEATURES

CONCEPT A - ATTACHED LABORATORY - 57° ORBIT

MISSION	
11	OCEANOGRAPHY OBSERVATORY DEVELOPMENT LABORATORY
6	GLOBAL HABITABILITY OBSERVATION LABORATORY
4	SPACE ENVIRONMENT FACILITY
5	EARTH OBSERVATION FACILITY

ELEMENT INTERFACE	FEATURES
GROUND OPERATIONS CONTROL CENTER	• GROUND TRACKING - EPHEMERIS PREDICTION - FLIGHT PLANNING • VOICE AND DATA LINK VIA TDRSS/MILITARY SAT COM • GROUND DATA ROUTING TO PAYLOAD/EXPERIMENT INVESTIGATORS • INVESTIGATOR REALTIME TELECONFERENCING
SPACE TRANSPORTATION SYSTEM - LAUNCH SITE - ORBITER	• CARGO INTEGRATION OF SPACE STATION MODULES, EXPERIMENTS, REPLENISHMENT ITEMS, PERSONNEL • INITIAL TRANSPORT PLACEMENT, ORBITAL ASSEMBLY VIA EVA • LONG-TERM LOGISTICS RESUPPLY - RENDEZVOUS AND DOCKING TRANSFER AND HANDLING PERSONNEL, SUPPLIES, EQUIPMENT. UP/DOWN
ATTACHED ENCLOSED LABORATORY	• STRUCTURALLY RIGID ATTACHMENT, POWER, COMMUNICATIONS AND DATA TRANSFER. DATA ANALYSIS AND EVALUATION. SHIRTSLEEVES ENCLOSED LABORATORY. BENCH/RACK MOUNT AND GIMBALLED POINTING MOUNTS FOR SENSORS. HANDS ON INTERACTION WITH EXPERIMENTS. PERSONNEL READY ACCESS TO/FROM HABITATION QUARTERS.
EXPERIMENT PALLET	• PALLET EXPERIMENTS REMOTE INTERACTION, CONTAMINATION CONTROLLED.

SPACE STATION PROGRAMS

TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

ARCHITECTURAL OPTIONS DEVELOPMENT AND ASSESSMENT

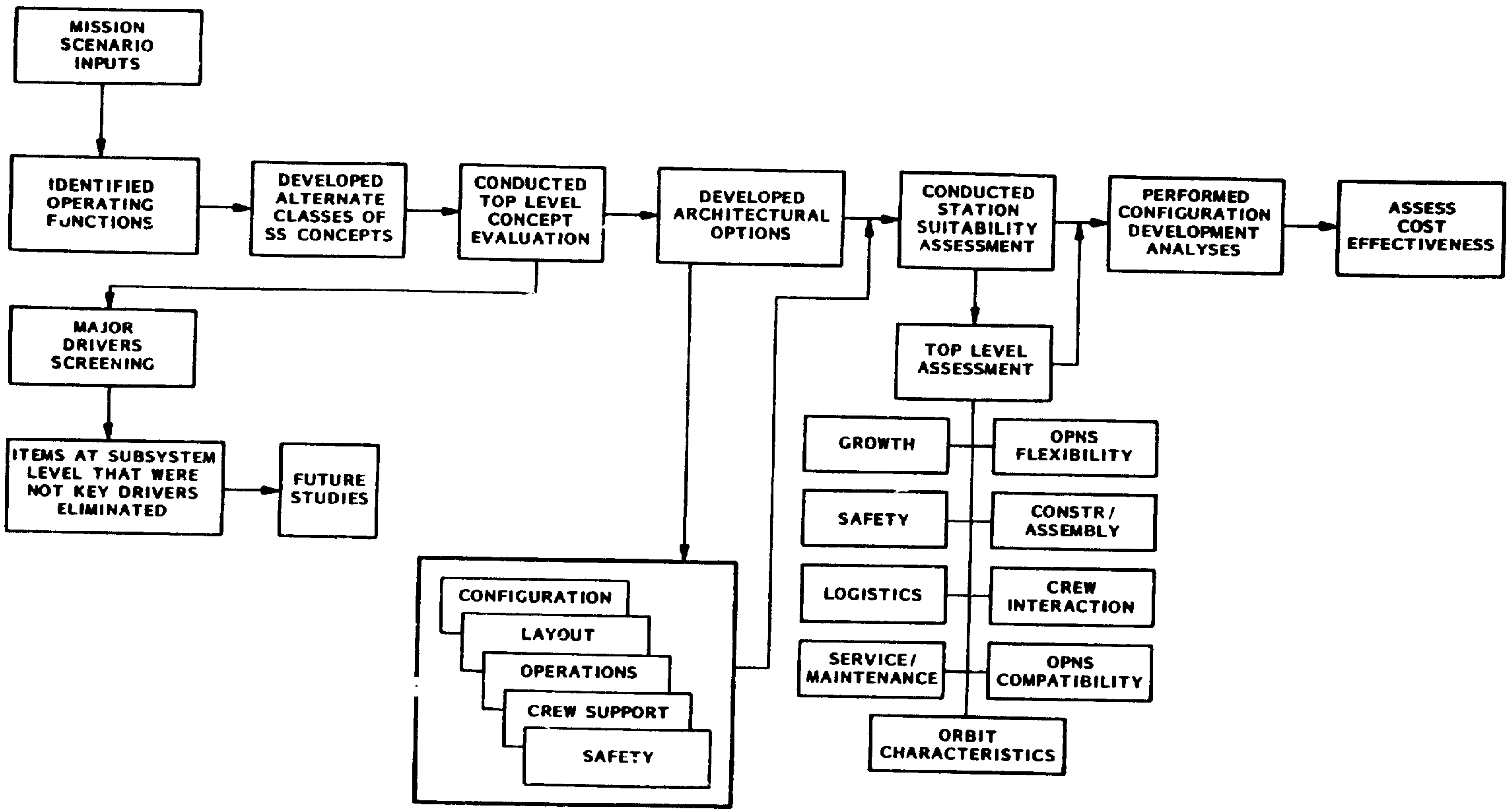
We analyzed fifteen (15) classes of potential space missions within the categories of Science, Applications, Commercial, US National Security and Operations. From these operations analysis space station system functions and architectural groupings were identified. On a basis of functional commonality and operations compatibility, we identified five top level system concepts and the system functional interfaces. These essentially define the space station systems to accomodate the mission sets that were evaluated.

This next section of our report describes the development and assessment of architectural options in accordance with the process as shown on this accompanying chart. Initially a top-level evaluation was performed of the alternate system concepts to identify the major influences on the station architecture. Since our emphasis during this study has been to concentrate on the conceptual framework for a space station rather than on detail design, we set aside most of the subsystem influencing factors as candidates for future studies. We did consider those subsystem drivers which will influence overall configuration arrangement and layout, such as habitation sizing and work area arrangements for personnel and for performing station satellite servicing and construction/assemblying operations.

Architectural options were explored from a standpoint of configuration, layout arrangement, operations activities, crew support and safety. Station performance capability was evaluated based on criteria such as growth, safety, logistics support needs, servicing and maintenance needs, orbital environmental needs. operational flexibility on orbit construction/assembly needs, crew interaction needs and operational compatibility with space infrastructure including space transportation elements and communication networks.

Results of the station suitability assessment were used in supporting configuration development analysis and cost effectiveness analysis to identify candidate space station configurations.

ARCHITECTURAL OPTIONS DEVELOPMENT AND ASSESSMENT PROCESS

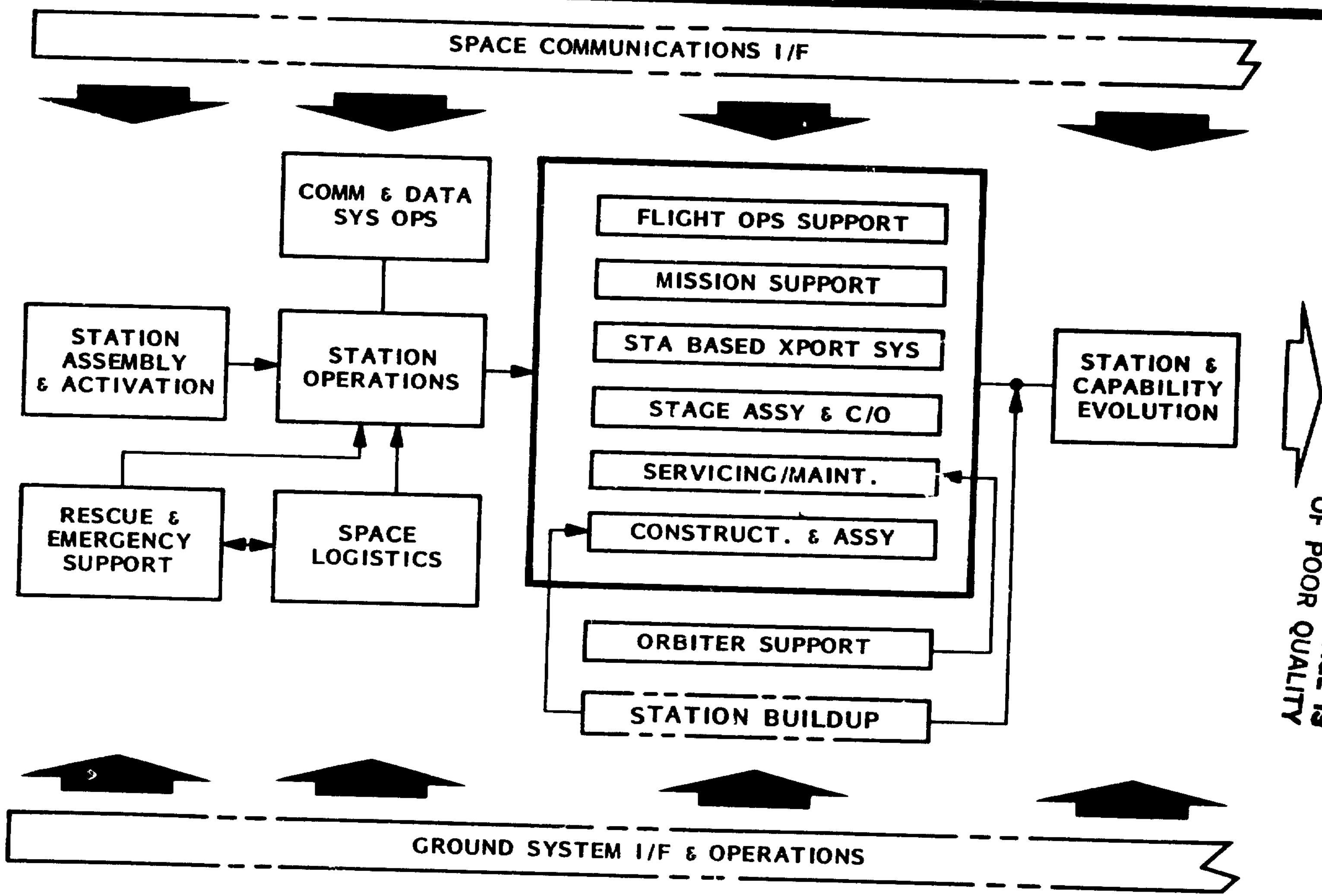


STATION OPERATIONS INFRASTRUCTURE

As the study evolved, it became more clear that the overall station operations infrastructure required early definition as a means of assuring that the functional needs would be identified and could then be amplified. The facing page illustrates in simplified form the basic station infrastructure as invisioned at this time. Of importance to note is the continuing operational interaction with the ground and space communications asset. Integral to this infrastructure are the National Security operations, however, that aspect is not covered herein and will be presented in an accompanying classified volume.

Two operational factors which, to date, have received less than adequate attention are the areas of rescue and emergency support, and space logistics (more aptly referred to as the integrated space logistics system). These two areas form an important part of the overall architectural definition and, as importantly, significantly influence the costing efforts. Accordingly, added effort was given to these areas to assure overall inclusion in the study.

STATION OPERATIONS INFRASTRUCTURE



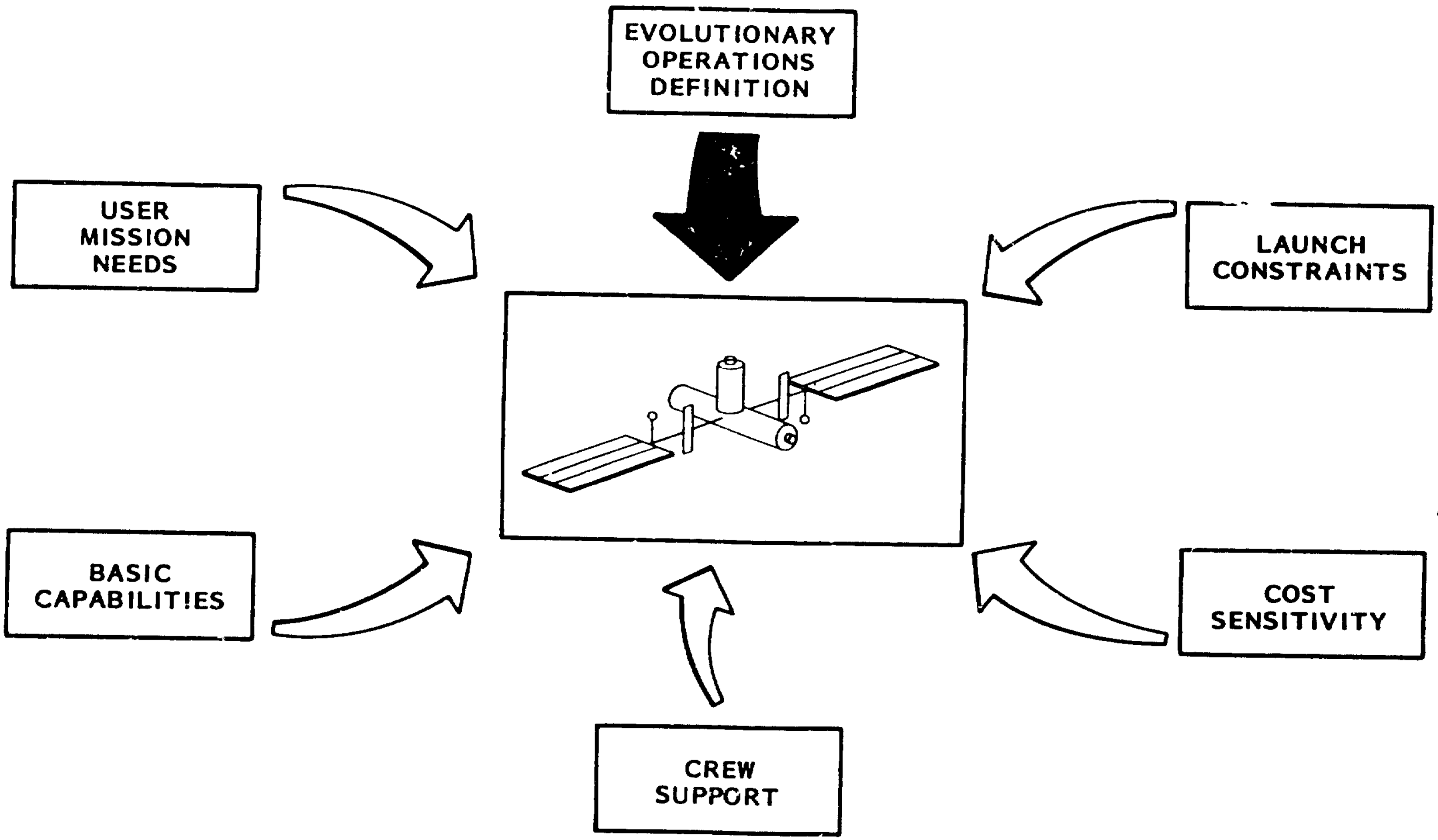
ORIGINAL PAGE IS OF POOR QUALITY

OPERATIONS APPEAR TO BE MAJOR DRIVER

As a result of the operations and functions definition effort, it became more and more apparent that these two factors were the primary drivers for the station. The facing page illustrates a simplified interaction of the major summarized synthesized station influencing factors. One of the most elusive factors in the study was cost due to the overall complexity and magnitude of this study element. Additionally, out-year funding estimates, program start-up dates, procurement ceilings, etc., all added to the costing 'challenge'. Nonetheless, when examining the station, it was determined that the build-up and/or evolution could be paced to the costing groundrules and implications. However, the operations and functions requirements loomed as the major driving factor on the station in that the basic operations/functions had to be inherently provided (even in a growth pattern) in order to meet mission needs and support requirements. Consequently, the architectural design effort was substantially influenced by the operational/function needs established early in the study. Obviously, certain of these operations and functions needs had greater impact that others and, as such, were given higher prioritization scores in the rating system since the majority of these needs were translated into top-tier design criteria, assumptions, and/or guidelines.

SPACE STATION PROGRAMS

OPERATIONS APPEAR TO BE MAJOR DRIVER



SPACE STATION PROGRAMS

TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

FUNCTIONAL NEEDS TRANSLATED INTO ARCHITECTURAL DRIVERS

Upon completion of the development of the basic scenarios, a number of station influencing impact factors were identified. This effort resulted in the identification of some 23 categories within which numerous sub-category impact drivers were listed. The opposite page illustrates these categories within which numerous sub-category items were examined. Each of the items was then evaluated and where possible quantitatve numbers/values, etc., developed for each. This permitted the analyst to then 'determine' the overall impact on the station through the use of a rating score (low-medium-high). The results of this analysis were then promulgated to the architectural design team and used as a basis for preparation of basic input criteria and guidelines.

The evaluation results and summary of this effort are presented in subsequent pages herein. The activity was also closely keyed to the configuration concept analysis and assessment effort, and provided the backbone of design inputs used in the architectural definition effort.

SPACE STATION PROGRAMS

FUNCTIONAL NEEDS TRANSLATED INTO ARCHITECTURAL DRIVERS

ENVIRONMENT	9
SHUTTLE MANIFESTING	10
LOGISTICS	11
POINTING & CONTROL	12
APP/DEPART ENVELOPES	5
STATIC [illegible] SSY	11
MODULARITY	9
HABITATS	12
ENCLOSED VESSEL	11
OPEN PLATFORM	10
APPENDAGES	15
MECH. PROVISIONS	12
CREW	17
COMM I/F	11
MISSION HDWR SUPPORT	15
SUPPORT ELEMENTS	30
SERVICING & STAGE SUPT.	16
SUPPORT SERV. & UTILITIES	14
SUPPORT SUBSTATIONS	16
CONSTRUCT & ASSY	13
SAFETY	12
VULNER/HAZARDS	13
ARTIFICIAL GRAVITY	9

OVER 280 INDIVIDUAL POTENTIAL STATION IMPACT INFLUENCERS EXAMINED

A. INFLUENCE IMPACT CHARACTERIZED FOR EACH CATEGORY ELEMENT
B. EACH IMPACT INFLUENCE RATED
- HIGH
- MEDIUM
- LOW

C. LOW ITEMS SCREENED OUT
D. HIGH/MED IMPACTS PRIORITIZED

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

MAJOR ARCHITECTURAL DRIVERS
(SUMMARY)

As a result of the extensive analysis and evaluation effort previously reported, a specific set of architectural drivers has been identified for the station. These drivers are illustrated on the opposite page and include operational, physical, dynamic, 'procedural', environmental, and programmatic. Each of the statements has been defined in sufficient detail so as to provide an impact characterization factor(s) for use in the architectural definition process.

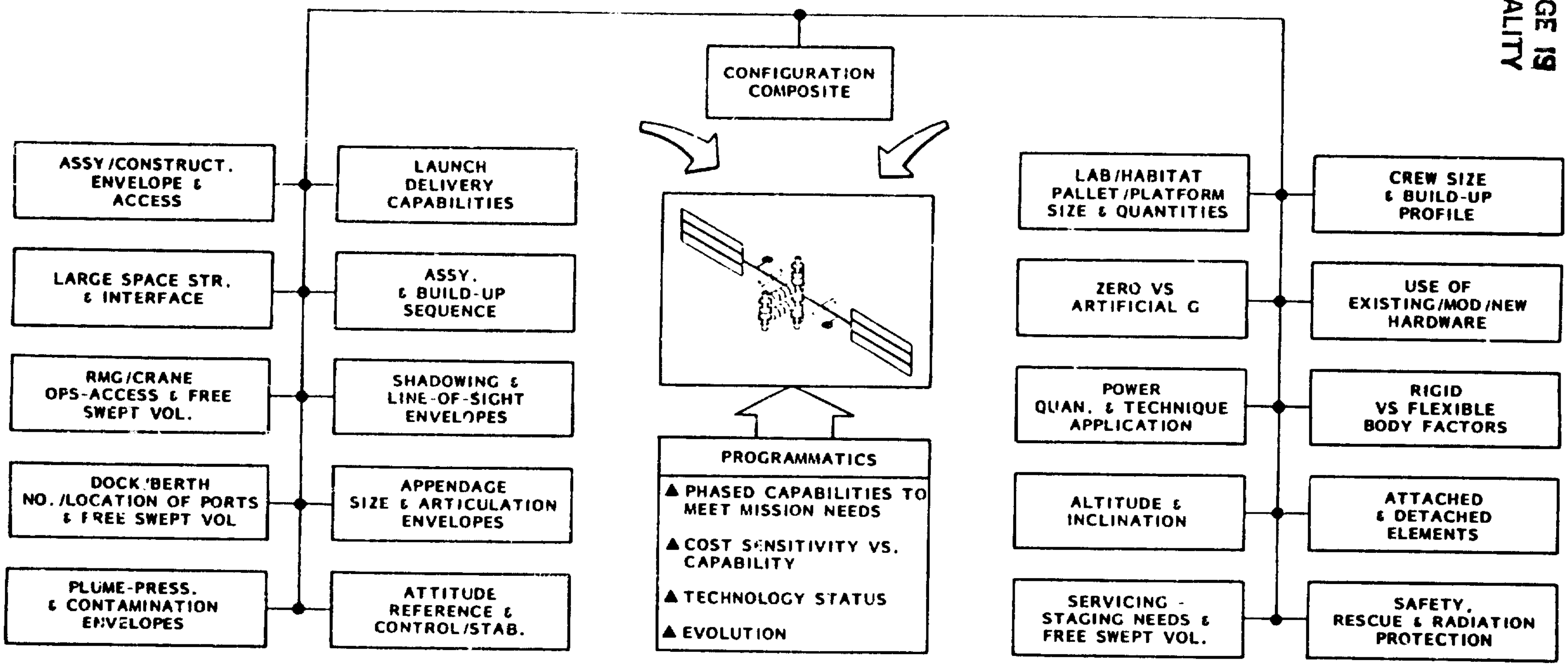
Of all areas considered, those factors associated with programmatics have been the most difficult to identify and/or define. In particular, those factors associated with cost have been most difficult to forecast for the NASA out-year schedules. Similarly, the downstream mission needs, as yet not fully defined, also promote concern relative to comprehensibility with respect to levels and credibility of depth. Evolution of the station is based on a myriad of parameters, issues, and current unknowns including cost; nonetheless, bogus ceilings can be established and used as a basis of departure. Thus, in concert with the operational, physical, dynamic, 'procedural', and environmental drivers, cost was used as a major driving element in the overall assessment of impact factors.

These factors were provided in summary from to the design team for incorporation as criteria guides used in the architectural definition process. Similarly, as the design progressed, these criteria were also used with the evolution rationale to aid in the station build-up sequence effort reported upon in subsequent charts.

SPACE STATION PROGRAMS

MAJOR ARCHITECTURAL DRIVERS (SUMMARY)

ORIGINAL PAGE IS
OF POOR QUALITY



Lockheed

CONFIGURATION CONCEPTS EVALUATION

The facing page presents the results of evaluation of 11 of the 32 space station configuration developed in this study. Results for the evaluation of the other 21 configurations are given in Attachment 2 to this report.

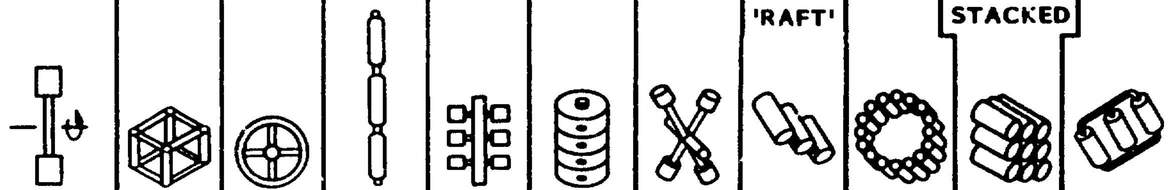
Each of the 32 concept configurations were subjected to a KTA evaluation to determine overall practicality, mission suitability, and utility. The evaluation criteria used was as follows:

1. Orbiter Considerations
   - No. of Orbiter launches
   - Config. fits cargo bay vol.
   - Adaptable to Orbiter support
2. Feasibility
   - Structural stability
   - Technical dev. practicality
   - Ease of on-orbit assembly
3. Flexibility
   - Permits large struct. assy.
   - Multiple docking ports & access
   - Adaptability to growth
   - Permits artificial g
   - Meets mission/operations needs
4. Programmatics
   - Permits existing hdwr. application
   - Cost sensitive & cost practical
5. Performance Capability
   - Meets mission needs
   - Allow 0 to partial g

Each concept was individually rated one against the other based on the above criteria. Scores were then summed for each configuration concept and the concepts rank ordered. Results of this evaluation are presented in the Architectural Concept Configuration Evaluation Summary chart following these charts.

SPACE STATION PROGRAMS

CONFIGURATION CONCEPTS EVALUATION



	Element Types \ Configuration Types	Interconnected Pier Mount: Dumbell	Ring/Spoke Mt.	Ring/Spoke Mt.	Longitudinal	Stacked: Hub-Tunnel Mount	Stacked	Radial Hub Mt.	Cluster Pac: 'Raft'	Cluster Pac: Tangential	Cluster Pac: Stacked	Cluster Pac: Tier Strongback
ORB. I/F	• NO. OF ORBITER LAUNCHES	9	6	3	8	5	6	5	8	3	3	6
	• CONFIG. FITS BAY VOLUME	9	8	2	9	8	5	7	9	9	9	9
	• MEETS LAUNCH WT. LIMITS	9	4	2	7	4	6	5	7	1	1	6
	• ADAPTABLE TO ORB. SUPPORT	8	9	6	7	9	6	6	8	9	9	9
FEAS.	• STRUCTURAL STABILITY	2	6	8	2	6	9	4	8	8	9	7
	• TECH. DEV. PRACTICALITY	5	6	3	8	9	6	9	9	8	8	8
	• ASSY EASE ON-ORBIT	9	4	2	7	6	9	4	8	5	5	6
FLEX.	• PERMITS LG. STRUCT. ASSY	3	9	3	4	5	7	6	8	8	8	9
	• MULTI-DOCK PORTS & ACCESS	5	9	2	5	8	7	7	7	9	9	8
	• ADAPTABILITY TO GROWTH	6	8	1	2	7	9	2	9	7	9	8
PROG.	• COST	7	5	2	8	7	7	4	8	6	6	7
	• EXIST. HDWR. APPLICATION	3	2	1	2	2	1	2	2	2	2	2
NEW	• MEETS MISSION NEEDS	1	8	1	7	8	7	4	8	7	7	8
	• ALLOW 0 TO PARTIAL G	9	1	9	1	6	1	9	1	3	1	1
		85	85	45	77	89	89	72	100	85	79	94

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

SERVICING/STAGE ASSEMBLY FACILITY

Twelve alternative servicing and stage assembly facility concept layouts have been prepared. Each concept incorporated a multi-functional capability to facilitate a variety of functional needs previously established in the operations/functions analysis section of Task 2 of this report. Basic functional capabilities include:

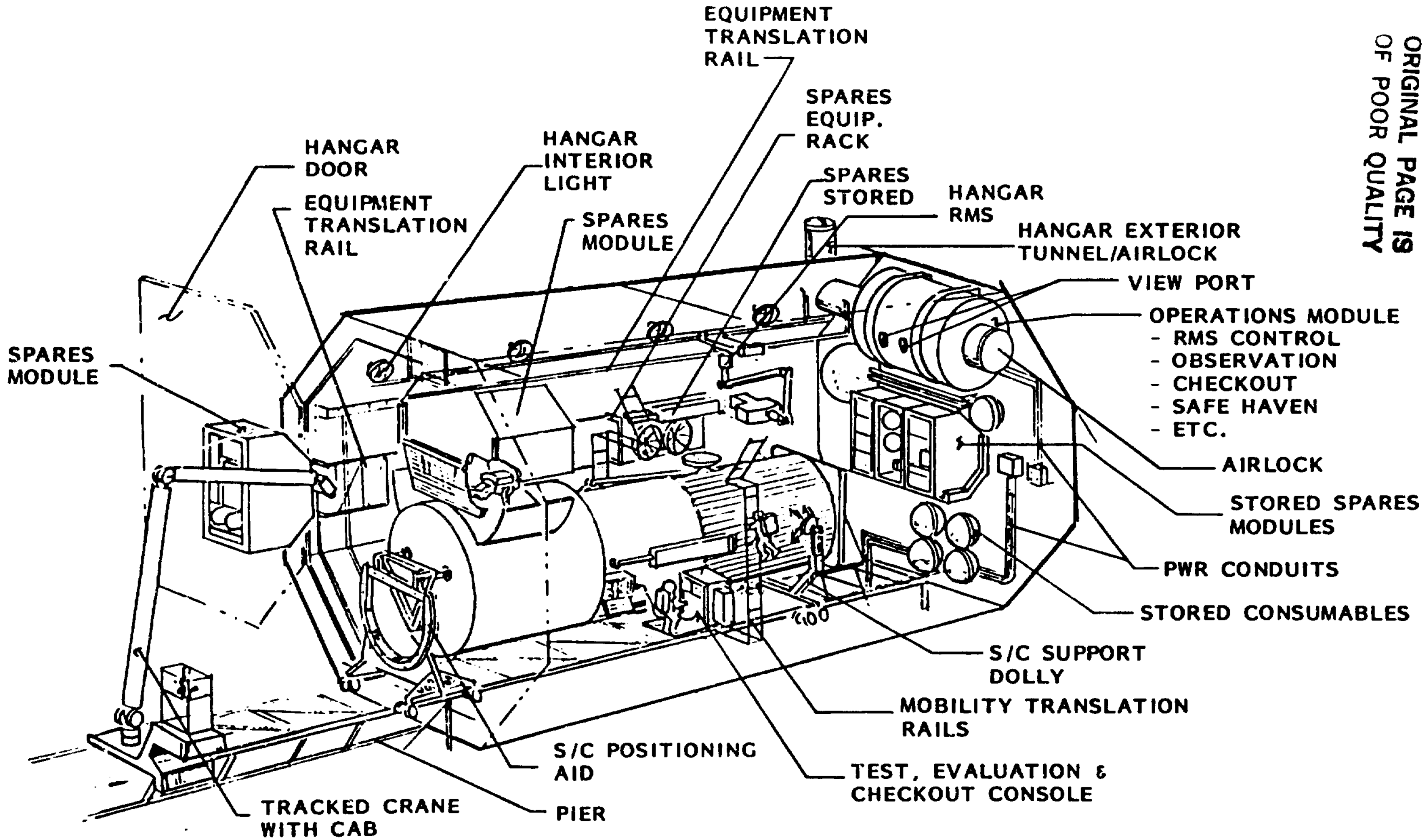
- Logistics resupply receiving
- Logistics fluids/pressurant receiving
- Operations module
- Spacecraft/stage handling equipment
- Transport & positioning rails
- Fixed & tracked RMS/Crane
- Spares (ORU's) handling aids
- Crew translation aids/restraints
- Illumination & CCTV aids
- Utilities services
- Checkout consoles (EV used)
- Rotation/tilt fixture

The facility shown opposite is a basic frame structure with the option of providing a 'screen-like' material around the entire assembly to assist in 0-g 'containment' operations. An option would be to additionally cover the structure with multi-layer insulation (MLI) to control both thermal and illumination environments. A hangar 'door' might also be provided to facilitate 'enclosure' of basic internal conducted functions. The facility would be attached to the main station via a 'pier' structural interface which also doubles as a track mounting platform for a mobil RMS and/or Crane used for spacecraft capture.

This concept can be added to or simplified as functional station needs are more firmly defined particularly with respect to amalgamation of functions (e.g., servicing and stage assembly) vs independent allocation of functions and associated support facilities. Considerable more effort must be allocated to this area of architectural definition and layout prior to fully understanding the station impact (architectural) involved in the incorporation of this station sub-element.

SPACE STATION PROGRAMS

CONCEPT FOR A SERVICING/STAGE ASSY FACILITY



PLUME IMPACT - SUMMARY

The facing page indicates a synthesized summary of the potential plume affects relative to station design and architectural considerations. Both plume pressure and contamination are of concern particularly relative to large appendages (solar arrays) and to highly contaminant sensitive sensors and instruments. As shown, direct plume impingement from the Orbiter at the closer approach distances, e.g., 10 to 100 ft can impose a significant plume impact on the station. Thus, Orbiter approaches which minimize plume impingement are highly desirable, however, such approaches consume considerably more Orbiter fuel than the other proximity operation techniques.

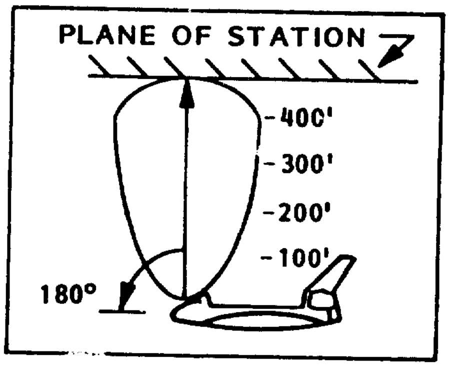
Thus, the engine ejecta constituant gases, particles, and thermal characteristics comprise an important concern to the station as does the overall plume pressure envelope. Further studies are needed to determine similar concerns associated with free flyers which incorporate active thruster systems used for docking with the station.

SPACE STATION PROGRAMS

PLUME IMPACT — SUMMARY

A. PLUME EFFECTS CAN IMPACT STATION:
1. DOCKING & SEPARATION
2. ON-ORBIT CONTROL OF:
   - ORBITER/STATION
   - STATION/HABITAT
   - STATION/STRUCTURE-PLTFM.
   - STATION/APPENDAGE
3. CONTAMINATION OF:
   - SOLAR ARRAYS
   - VIEW PORTS
   - SENSORS
   - CRITICAL SURFACES
4. EFFECTS DEPENDENT ON SUCH FACTORS AS:
   - MASS DISTRIBUTION
   - GEOMETRY
   - ITEM CONTAM.SENSITIVITY
   - VEHICLE PLUME ENVELOPES
   - MATERIAL PROPERTIES

EXAMPLE



5. POTENTIAL 90° DIRECT PLUME IMPACT ON STATION REFERENCE PLANE WITH PRCS:

FACTOR \ DISTANCE	100 FT	200 FT	300 FT	400 FT
PRESSURE (LB/FT^2)	10^{-5}	10^{-6}	10^{-7}	10^{-7}
IMPINGMT FORCE (LB/FT^2)	10^{-3}	10^{-3}	10^{-4}	10^{-4}

6. PLUME PRESSURE IS SIGNIFICANT:
   - IMPACT ON SOLAR ARRAYS
   - CONTAMINATION ON OPTICAL/SENSOR PALLET
   - TORQUE DISTURBANCES MINOR BUT EVIDENT

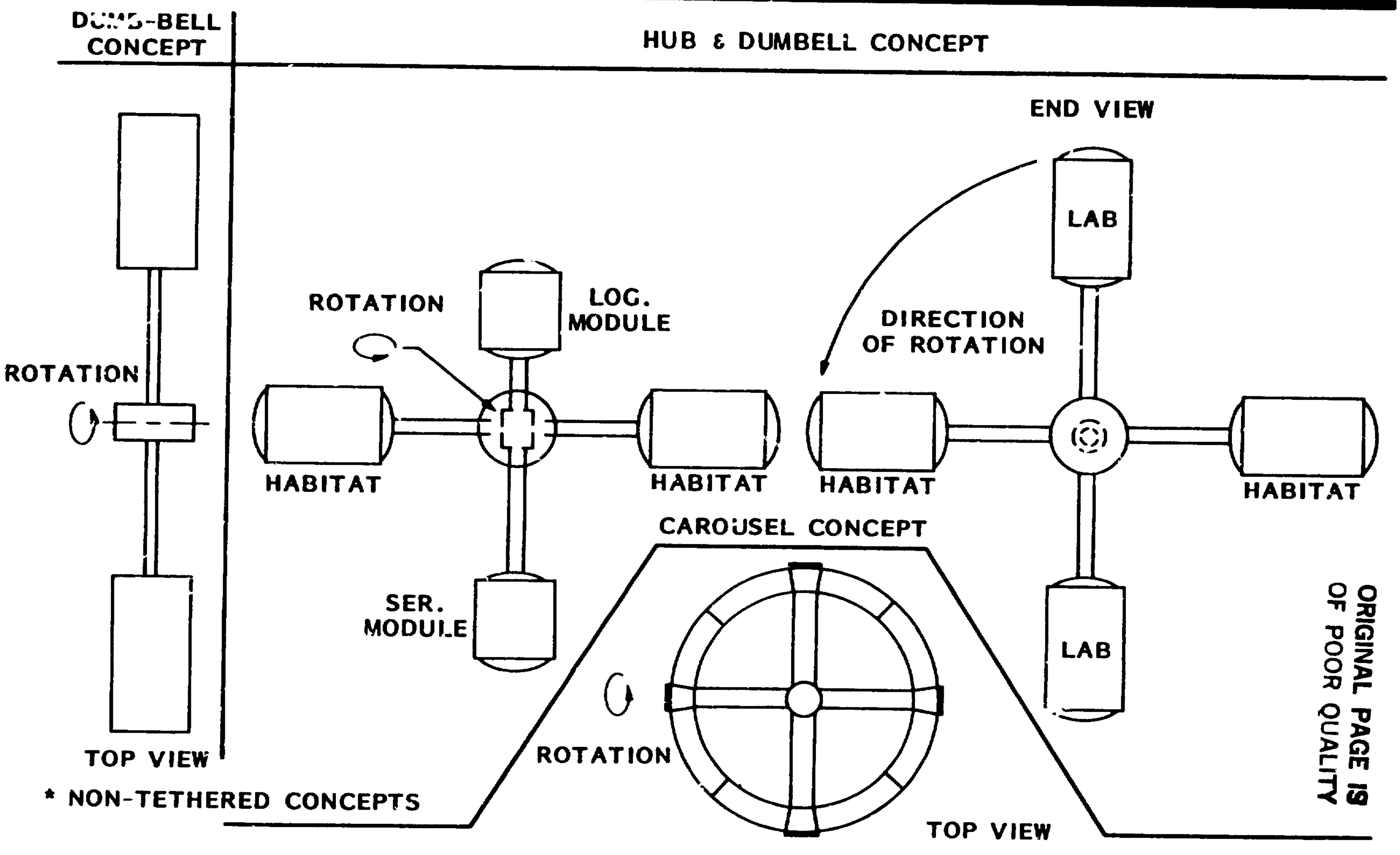
Lockheed

PARTIAL GRAVITY STATION EXAMPLES - SCHEMATIC

The opposing page presents three selected rotation space station schematic representations. Each rotate about a central hub, thereby providing partial gravity at the extremeties, e.g., outer habitat/lab or ring segment. Numerous studies indicate that the radius from the rotational hub must be, at a minimum, at least 100 ft. and preferably 200 ft. for a gravity of over 0.5 g's and a rotation rate of about 4 rpm in order not to increase the crew persons' weight in excess of 15 to 20% due to the Coriolis and velocity-toward-rotation effects. Thus, as can be seen in the facing figures, significant impact on the station architecture is encountered in order to provide the necessary distance from the rotational hub. This constraint and others are further elaborated upon in the next pages.

SPACE STATION PROGRAMS

PARTIAL GRAVITY STATION EXAMPLES—SCHEMATICS (SELECTED EXAMPLES)



ORIGINAL PAGE IS OF POOR QUALITY

TETHER IMPLICATIONS & ARTIFICIAL GRAVITY

The following two charts indicate the nature of the utilization of 'tethered' spacecraft and/or elements to the station. Initial utilization of the tether was with the Gemini 6/7 Mission wherein the spacecraft was tethered to the Agena vehicle. Since that time, numerous studies have been made relative to the use of tethers for advanced space programs. Two recent study contracts have resulted in the selection of a U.S. aerospace contractor working in concert with a European contractor to develop a tethered satellite 'suspended' from tne orbiter. The next two pages briefly outline the advantages of the tethered station-spacecraft, applications of artificial G in the station, and general applications of artificial G for various tethered elements. Results of this analysis have been provided for the basic station configuration layout studies associated with tethered elements.

Of particular interest to this study were three aspects of the early analysis of tethers and are (1) Ability to 'reel in/out' pallets/platforms to support the station; (2) Possible power availability; and (3) Tether 'release energy' for 'launch or reentry' trajectories. Nonetheless, it is felt that additional study be applied before more substantial application of the tether principals be incorporated into the evolution of the station architectural framework.

SPACE STATION PROGRAMS

TETHER IMPLICATIONS & ARTIFICIAL GRAVITY

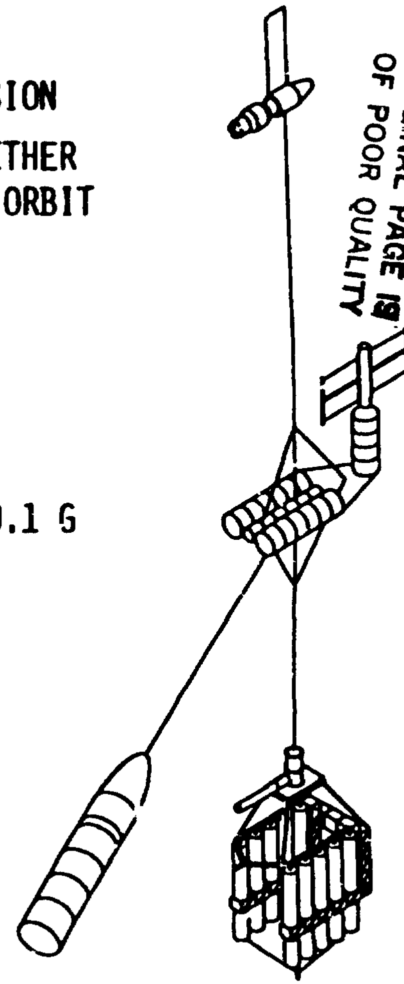
A. TETHERING SPACECRAFT WAS INITIALLY ATTEMPTED ON GEMINI 6/7 MISSION

B. LEVEL OF G (GRAVITY) OBTAINABLE IS PROPORTIONAL TO LENGTH OF TETHER FROM CENTER OF SYSTEM MASS & EQUALS 4×10^{-4} G/KM IN LOW EARTH ORBIT

C. ADVANTAGE:
1. FREE OF THE LARGE 'FLOOR TO CEILING' G VARIATIONS AND
2. DEBILITATING/UNPLEASANT CORIOLIS EFFECTS
3. TWO AXIS STABILIZATION

D. G-LEVEL ATTAINABLE:
1. TETHER BECOMES SIGNIFICANT PART OF STATION MASS TO ACHIEVE 0.1 G
2. TETHER MASS IS RELATIVELY MINOR FOR 0.05 G's OR LESS

E. APPLICATIONS AT 0.01 TO 0.1 G IN A STATION:
1. SIMPLIFICATION OF CERTAIN CREW AIDS/ACOUTREMENTS (IVA)
2. FACILITATE LIQUID'S FLOW (SHOWER/TOILET) - (IVA)
3. MINIMIZATION OF SMALL LOOSE FLOATING OBJECTS (IVA)
4. ENHANCEMENT OF TOOL USE VIA TETHER ELIMINATION (IVA)
5. VARIABLE G FOR PHYSICS/LIFE SCIENCE/COMMERCIAL RESEARCH



Lockheed

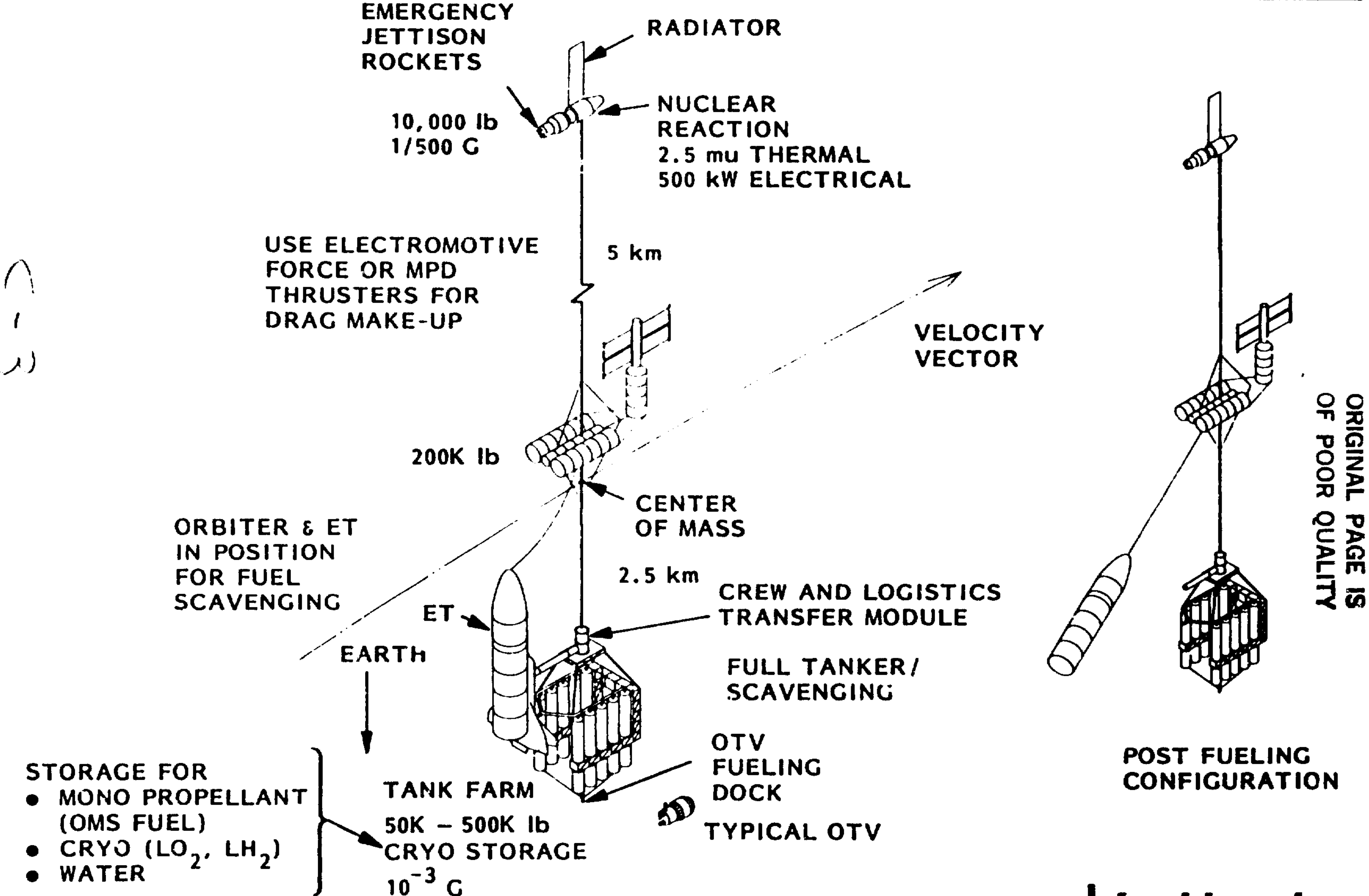
SPACE STATION TETHER CONCEPTS

Two important applications of the tether are shown in the figure on the facing page. One important application of a space station will be propellant storage for use in OTVs and for logistics support to satellites. A key challenge is orienting fluids in a zero g environment. The use of a tether to support a propellant farm provides a solution to this challenging technical issue. A 2.5 km tether will create 10^{-3}g, sufficient to orient propellants thus making the fluid transfer possible with a minimal difficulty. In our concept the space shuttle orbiter with the external tank attached could be docked to the propellant farm to allow scavenging of the residual propellant. The orbit mechanics of this berthing operation need to be studied from the point of view of orbiter safety since the tank farm is moving in a slightly different (slower) orbital speed than the orbiter at that altitude. The differences in velocity are small and should be accommodated with minimal difficulty. Payloads could be removed from the orbiter while berthed to the tank farm and tranferred to the space station by a tether. The propellant farm has been sized to 500 klb to accommodate 12 missions per year at 25klb per service mission.

Another application of tethers is to support a nuclear reactor. Initial station configurations will use solar arrays for power ranging up to 50 kw. Long term high power requirements will be required and a nuclear reactor is an ideal choice for that purpose. By placing the reactor on the end of a tether the shielding requirements are dramatically reduced and safety of the system is enhanced. Analysis has shown that for transmission of 100 kW, the tether, operating at 10 KV, will weigh less than 1000 lbs. For a 300 KW system, the tether weight for a 10km tether will be 6000 lbs. The reduction in shielding weight more than offsets the increase in tether weight as the reactor is moved away from the station.. The tether also provides the opportunity to use electromotive force induced by a current cutting the earths magnetic field as a means of providing for drag makeup and orbit change. Approximately 0.2 lbs thrust is obtained for 15 kw. Details and impact of the tether design on the overall system need to be assessed but it is clear that this concept offers some startling new opportunities for the space station configuraiton.

SPACE STATION PROGRAMS

TETHER CONCEPTS



ORIGINAL PAGE IS
OF POOR QUALITY

C-3

Lockheed

SPACE STATION PROGRAMS

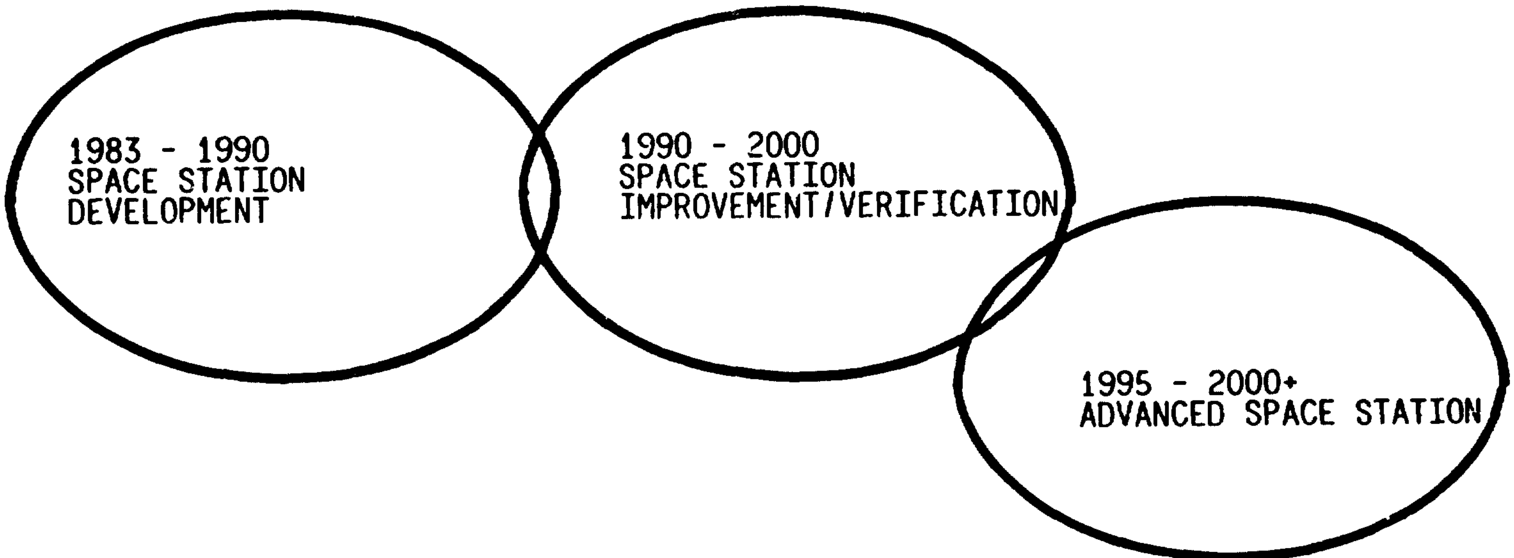
TASK 2—MISSION IMPLEMENTATION CONCEPTS

2.1 MISSION SCENARIO ANALYSIS AND ARCHITECTURAL CONCEPTS
2.2 ALTERNATIVE SYSTEMS CONCEPTS
2.3 MISSION OPERATIONS ARCHITECTURAL DEVELOPMENT
2.4 ARCHITECTURAL ANALYSIS TRADES
2.5 EVOLUTION
2.6 CONFIGURATION
2.7 TECHNOLOGY DEVELOPMENT
2.8 CONCLUSIONS

Lockheed

SPACE STATION PROGRAMS

TECHNOLOGY DEVELOPMENT MISSIONS



EMERGING

THROUGH
SHUTTLE
R&D/DEMO

CONTINUING

THROUGH
STATION
BASIC
R&D/DEMO

FUTURE

THROUGH
STATION
ADVANCED
R&D/DEMO

Lockheed

TECHNOLOGY DEVELOPMENT MISSIONS

The following pages list technologies requiring development and demonstration in a space environment. These technologies are all oriented toward the capabilities required for a large (evolved) Space Station in the mid 1990's. Time phasing of the TDMs has not been done. The TDMs have been identified as to whether they are of critical need to the Space Station or whether they have a high potential pay-off through performance, cost or weight.

SPACE STATION PROGRAMS

TECHNOLOGY DEVELOPMENT MISSIONS

SUBSYSTEM	TECHNOLOGY DEVELOPMENT MISSION	CRITICAL NEED	HIGH POTENTIAL PAYOFF
STRUCTURES & MECHANISMS	LARGE STRUCTURES CONSTRUCTION	X	
	PRECISION STRUCTURE ASSY	X	
	LARGE ANTENNA ASSEMBLY & DEPLOYMENT		X
	LARGE STRUCTURE INTERACTION WITH ACTIVE CONTROL SYSTEM	X	
	REMOTE MANIPULATOR ARM & USE IN ASSY/SERVICING	X	
PROPULSION/ PROPELLANT MANAGEMENT	DEMONSTRATE LONG TERM SPACE CRYOGENIC STORAGE	X	
	RELIQUIFICATION VERIFICATION	X	
	PROPELLANT TRANSFER DEMONSTRATION - CRYO/BIPROPELLANT	X	
	DEMONSTRATE REMOTE PROPELL LINE CONNECT/DISCONNECT		
ATTITUDE CONTROL	VERIFY ADAPTIVE CONTROL OF LARGE FLEXIBLE STRUCTURE	X	
	DEMONSTRATE AUTONOMOUS CONTROL OF OTV	X	

Lockheed

SPACE STATION CONCEPTS TO DEVELOP TECHNOLOGIES

From the technologies tabulated in the previous charts and the Alternative Space Station Systems concepts developed earlier in Task 2, a compatibility analysis was performed to define which Space Station Concept(s) can be used to verify or develop the needed technologies. The grouping often indicates the importance of a technology to the viability of station concept to be able meet its functional requirements.

Analysis results indicate that no single Space Station Concept can be used to satisfy the verification or development of these identified technologies.

SPACE STATION CONCEPTS TO DEVELOP TECHNOLOGIES

TECHNOLOGIES THAT NEED DEVELOPMENT	A – ATTACHED LAB, 57 DEG	B – ATTACHED LAB, 28-1/2 DEG	C – DETACHED FACILITIES, 28-1/2 DEG	D – LEO, SERVICING, 28-1/2 DEG	E – DOD, 28-1/2 DEG
• ADVANCED PROPULSION					
– MPD	X	X	X	X	X
– ION			X		
– LOW THRUST CHEMICALS			X	X	
– HIGH PERFORMANCE STORABLES	X	X	X	X	X
• ADAPTIVE CONTROL SYSTEM FOR LARGE, FLEXIBLE STRUCTURE	X	X	X	X	
• AUTONOMOUS CONTROL FOR PROXIMITY FREE FLYERS					
– PLATFORMS			X	X	
– OTV	X	X	X	X	
• LARGE SOLAR ARRAYS					
– DEPLOYMENT	X	X	X	X	
– PERFORMANCE					
– LIFE					
– MAINTENANCE					
– SOLAR CELL IMPROVEMENTS					
• NUCLEAR TECHNOLOGY					
– REACTOR		X	X		X
– SHIELDING					
– THERMOELECTRIC CONVERSION					
– HEAT REJECTION					

The column heads are grouped under the heading SPACE STATION MISSION CONCEPTS.

ORIGINAL PAGE IS OF POOR QUALITY

SPACE STATION PROGRAMS

TASK 3 - COST AND PROGRAMMATIC ANALYSIS

3.1 BENEFITS

3.2 COST, SCHEDULE AND FUNDING

Lockheed

THE LANGUAGE OF BENEFIT ASSESSMENT

Orderly discussion of Space Station benefits requires a common linguistic framework. A useful beginning is the definition of a benefit from Webster's New International Dictionary (Second Edition):

"Whatever promotes welfare; advantage; profit."

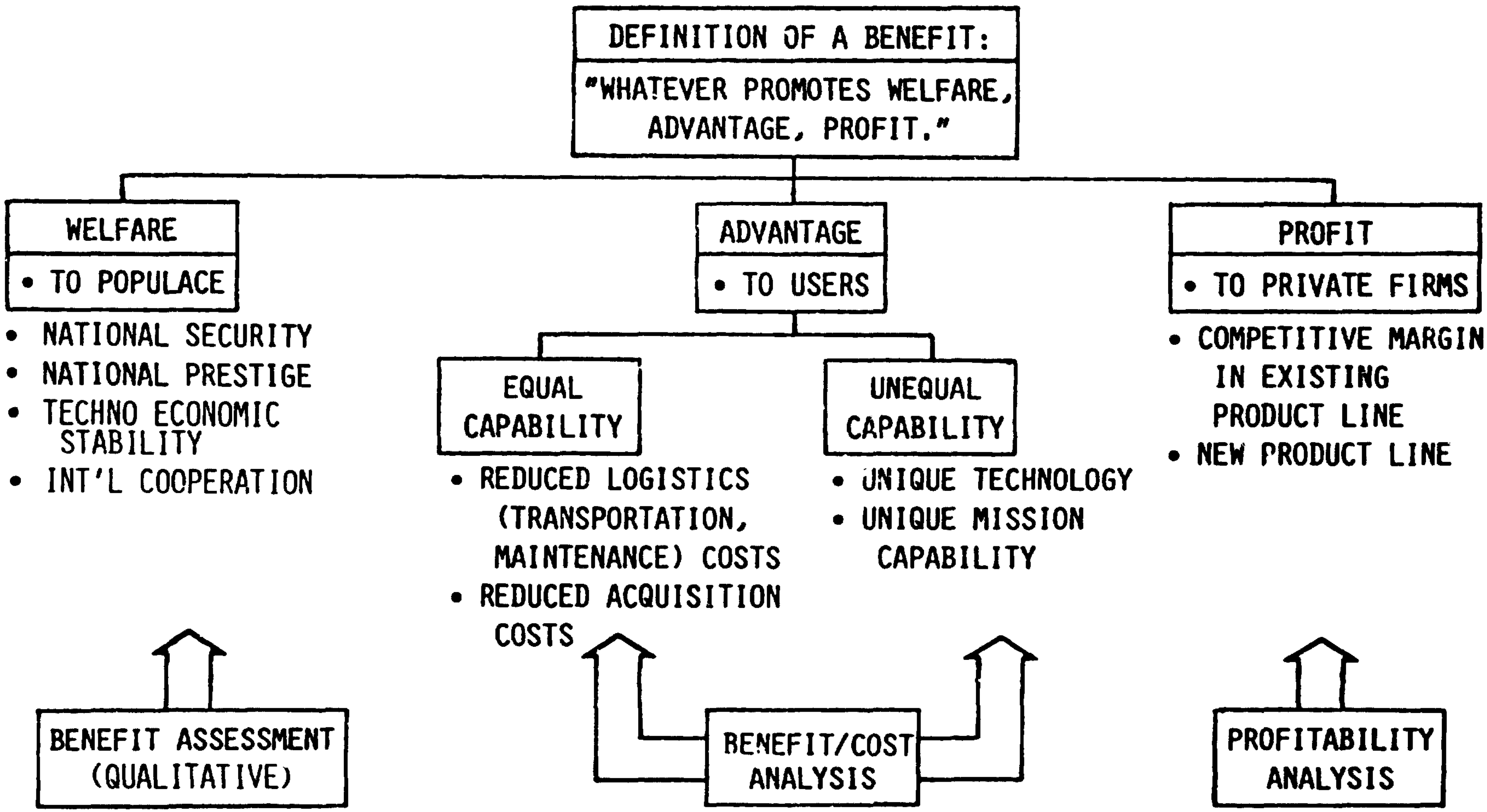
This definition suggest three convenient classifications for benefits. Each class benefits a different group and each is assessed in a different way. 'Welfare' benefits accrue to the populace at large, either nationally or internationally. They are factors that motivate decisions, yet are not used to justify these decisions analytically. This is because welfare benefits are the least tangible of all three classes and hence are difficult to quantify.

'Advantage' benefits accrue to the users of a system such as Space Station who have a job to be done and have alternative ways to do this job. The alternatives may be either of two types, i.e., 'equal capability' or 'unequal capability'. In the first case, the mission capability of alternatives (payload capability, data return, etc.) is approximately equal andlife cycle cost becomes the discriminator between approaches. In the unequal-capability case, the mission performance of alternative approaches is significantly different and cost is just one factor in selection of a preferred approach. For both of these advantage-type benefits, the techniques of cost-benefit analysis apply.

'Profit" type benefits, as defined here, accrue to a commercial firm. These are the competitive margins that can be realized with a new venture. They are quantified using profitability analysis, and such measures as return on investment and cash flow. Such benefits are not the focus of this analysis.

SPACE STATION PROGRAMS

THE LANGUAGE OF BENEFIT ASSESSMENT



Econon Lockheed

SOME QUALITATIVE BENEFITS

The benefits categorized as 'welfare' type in the preceding figure are qualitative rather than quantitative. This figure lists some of the qualitative Space Station benefits that have emerged in this study.

One category of these benefits arises from the fact that the Space Station is the largest open program likely to occur in the next decade. The sheer size of the Space Station program makes possible:

> Commercialization of space on a large scale, even to the point of contemplating space 'industrial parks'.
>
> International cooperation in which participants can develop elements of significant size (e.g., whole modules) rather than subsystems or assemblies.
>
> The establishment of a technology and manpower base large enough to buffer uncertainties in national policy.

Another category of non-quantifiable benefits arises from the national security advantages of a manned presence in space. The U.S. has recognized that a presence in otherwise uninhabitable places such as Antarctica adds an intangible sense of cognizance in areas where national sovereignty cannot be claimed. And if, in such a relatively inaccessible area a national command authority can survive better than on earth, then the assured continuation of our defense can be made more visible.

The list of qualitative benefits on this figure is representative but not comprehensive. This effort must continue until a policy on Space Station development is established.

SPACE STATION PROGRAMS

SOME QUALITATIVE BENEFITS

BENEFITS DUE TO STATION 'CRITICAL MASS'

- UNIQUE FRAMEWORK FOR SPACE INDUSTRIAL PARK
- 'FLYWHEEL' TO PRESERVE TECHNOLOGICAL & INDUSTRIAL BASE
- LARGE ENOUGH FOR SIGNIFICANT INTERNATIONAL PARTICIPATION
- UNFORESEEN SPINOFFS TO CIVILIAN ECONOMY

BENEFITS TO NATIONAL SECURITY

- U.S. CONTINUING PRESENCE IN SPACE (ANTARCTICA ANALOGY)
- SURVIVABLE NATIONAL AUTHORITY
- 'HIGH-GROUND' OBSERVER

SAFETY BENEFITS

- 'SAFE HAVEN' FOR STS CREWS

CASE STUDY OF LOGISTICS ADVANTAGES

The next three figures summarize a case study in benefits quantification that centered on the relative logistics efficiency of spacecraft servicing with an Orbital Transfer Vehicle (OTV). The specific program selected for analysis was the Integrated Tactical Surveillance System (ITSS), a program that has been analyzed in depth by Lockheed. The ITSS comprises orbital constellations of surveillance satellites. The procurement of these satellites can be reduced by extending their lifetime through scheduled servicing over the operational life of the program. In previous sections of this report, it was established that energy requirements for orbital transfer from a Space Station to a satellite are reasonable at nodal coincidence. Consequently the analysis was limited to scheduled servicing rather than unscheduled maintenance.

The alternative servicing modes considered in this case study span a range of options available with the OTV, as follows:

Servicing the ITSS satellites in place using a ground-based OTV

Servicing the ITSS satellites in place using a space-based OTV that operates from a Space Station

Using the space-based OTV to ferry the ITSS satellites to/from the Space Station for servicing

Conclusions of the analysis may be considered conservative because of the following assumptions:

Scavenging of External Tank propellants was not assumed for the space-based OTV. Such scavenging, if feasible, would magnify the cost advantage of the space-based system by providing essentially 'free' propellants with each STS resupply flight

The space-based OTV was not credited with potential improvements in mass fraction that might be realized through orbital basing of an OTV. This would affect the payload capability of the various OTV concepts

The ground-based OTV was not charged with the cost of a retrieval flight, i.e., it was assumed that the same shuttle used to deliver the OTV could wait on orbit until ITSS servicing was completed, then return to earth.

CASE STUDY OF LOGISTICS ADVANTAGES

CASE SELECTED FOR STUDY:

- ITSS PROGRAM
- CONSTELLATION OF 24,000 LB. SATELLITES
- 1400 NM ALTITUDE

GROUNDRULES:

- NO ET PROPELLANT SCAVENGING FOR SPACE-BASED OTV
- SCHEDULED ITSS SERVICING
- SPACE-BASED OTV FLIES ONLY AT NODAL COINCIDENCE

ALTERNATIVES EVALUATED:

- ITSS SATELLITES SERVICED AT 1400 NM BY GROUND-BASED OTV
- ITSS SATELLITES SERVICED AT 1400 NM BY SPACE-BASED OTV
- ITSS SATELLITES CARRIED TO/FROM STATION BY SPACE-BASED OTV

SAVINGS WITH SPACE-BASED OTV

SCHEDULED SERVICE MISSIONS

In scheduled servicing of an ITSS orbital constellation, the advantage of a space-based OTV over a ground-based OTV lies in fully-efficient use of the Space Transportation System. For each ITSS service mission, the ground-based OTV and its servicing payload must be launched from the earth; in so doing, the reusable OTV and payload could easily occupy 75 percent of Orbiter cargo bay length, thereb, incurring a dedicated flight charge. (Expendable OTV concepts, while shorter, cost a significant fraction of the Shuttle price per flight.) Moreover, if the ITSS servicing takes longer than the nominal Orbiter staytime, extra charges could be incurred for the extra stay or for a dedicated retrieval flight.

By contrast, the space-based OTV operates with a Space Station propellant depot which is at the end of an efficient logistics pipeline. The depot is resupplied using nondedicated Shuttle flights that are fully loaded. The OTV then draws from this store only enough propellants to perform ITSS servicing and return to the Station (15,500 lb for 1400 nautical mile orbit). This is less than one third of an equivalent shuttle flight per servicing mission.

SPACE STATION PROGRAMS

SAVINGS WITH STATION-BASED OTV

SCHEDULED SERVICE MISSIONS

	GROUND-BASED OTV	STATION-BASED OTV
SHUTTLE UTILIZATION	DEDICATED DELIVERY MODE: • ONE FLIGHT SCHEDULED PER SERVICE MISSION • LOAD FACTOR VARIABLE RETURN MODE: • DEDICATED RETRIEVAL FLIGHT • <u>OR</u> FLIGHT OF OPPORTUNITY • <u>OR</u> SHUTTLE STAYTIME EQUAL TO MISSION DURATION	DEPOT RESUPPLY MODE: • FLUIDS, EQUIPMENT RE-SUPPLIED ON SPACE-AVAILABLE BASIS • LOAD FACTOR 100%
OTV UTILIZATION	NOMINAL PROPELLANT LOADING	'TAILORED' PROPELLANT LOADING FOR EACH MISSION

Econon Lockheed

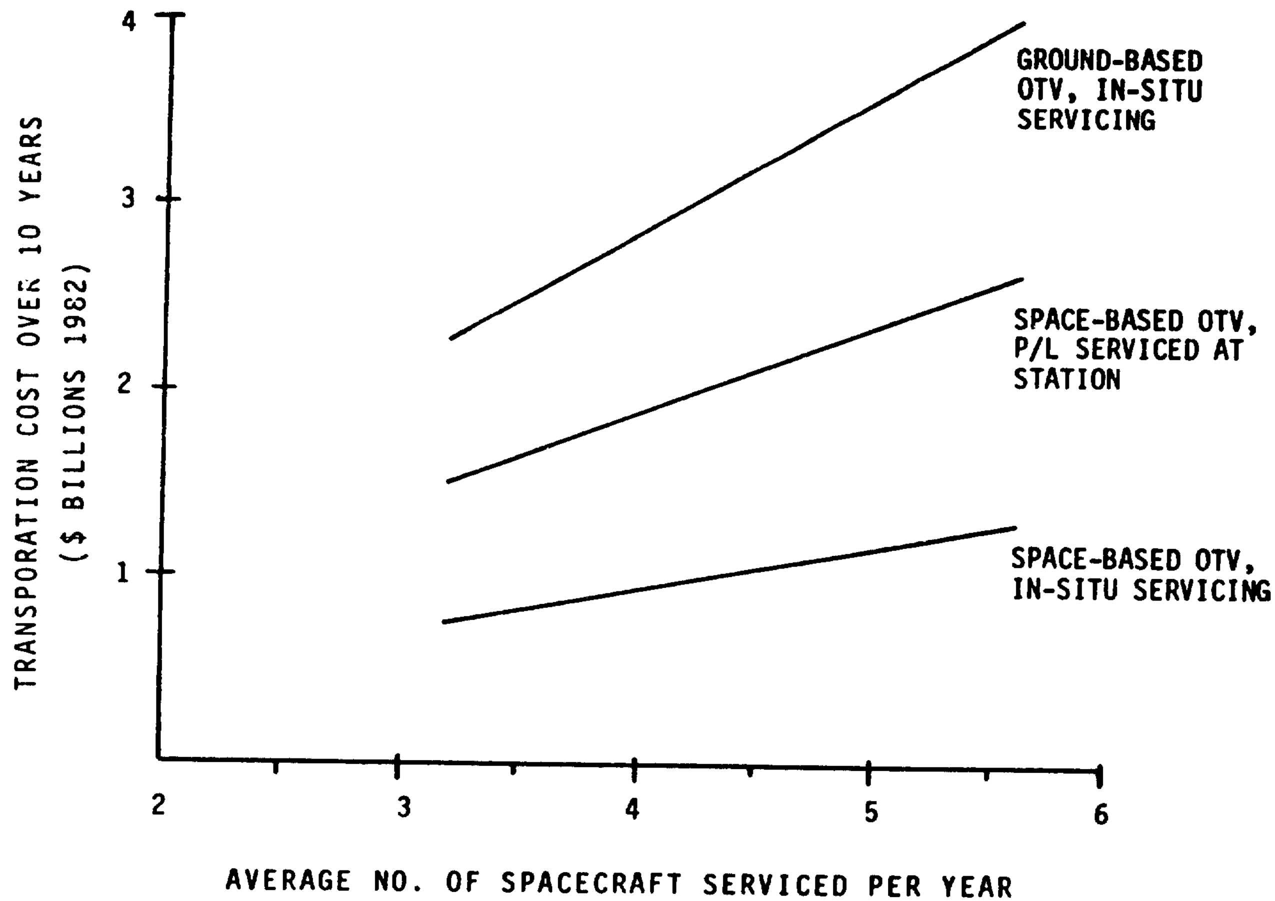
GROUND-BASED VS STATION-BASED OTV SERVICING

COST OF RECURRING TRANSPORTATION

A parametric approach was used in analyzing the relative costs of ground-based and Space-Station-based servicing systems. The measure of cost was total recurring Space Transportation outlay over ten years. Concept-to-concept differences between OTV flight operations costs were judged to be small; hence, these costs were omitted. The independent variable was chosen as the average number of ITSS spacecraft serviced in a year; this figure combines the total number of spacecraft with the average frequency of servicing.

Results of this analysis show that both of the space-based OTV systems are signficantly lower in cost for ITSS servicing than the ground-based system. Moreover, these savings are of a magnitude for this one mission (roughly $2.6 billion at the high end) to offset an appreciable amount of Space Station acquisition costs.

GROUND-BASED VS. STATION-BASED OTV SERVICING
(COST OF RECURRING TRANSPORTATION)



OBSERVATIONS ON BENEFITS

In benefit studies performed to date, the area of STS and OTV enhancement is emerging as a source of quantifiable support for the Space Station. Moreover, these results are decoupled from feasibility issues (such as ET scavenging) that have diverted attention from the justification of a Space Station.

The case study method continues to emerge as a key to realistic and traceable quantification of Station benefits. In this method, realistic mission scenarios are formulated, and alternative systems are defined both with and without Space Station support. The acquisition, operation and transportation costs of each alternative are compared and any net savings for the Space Station supported alternative are counted as benefits. The case study method is too detailed for quantifying total Space Station benefits, but should instead be used to establish the trends in cost/benefit analysis.

OBSERVATIONS ON BENEFITS

STATION-BASED OTV REALIZES TANGIBLE BENEFITS:

- SCENARIO IS FOR SCHEDULED SERVICING OF SATELLITE NETWORK
- SAVINGS INDEPENDENT OF ET SCAVENGING

ADDITIONAL BENEFITS ARE STILL TO BE EXPLORED:

- PAYLOAD EFFECTS
- ONBOARD DATA EVALUATION
- TEST BED HARDWARE DEVELOPMENT

CASE STUDY IS METHOD FOR BENEFIT QUANTIFICATION:

- DEFINE OPTIONS
- COST EACH AND MEASURE SAVINGS

SPACE STATION PROGRAMS

TASK 3 - COST AND PROGRAMMATIC ANALYSIS

3.1 BENEFITS

3.2 COST, SCHEDULE AND FUNDING

Lockheed

COSTING GROUNDRULES/ASSUMPTIONS

Emphasis in the cost analysis was on identifying cost drivers, uncertainties, and evolutionary trends. The estimates presented here cover development, production, operation and deployment of the reference Lockheed Space Station evolutionary architecture. The estimates exclude costs for development and support of Station payload costs. Likewise, costs for acquisition and operation of the OTV and Teleoperator Maneuvering System were omitted from the cost tabulations in this section even though they were used in the benefits analysis.

The reference costs presented here incorporate the $83 million per flight STS user charge, while the $117 million per flight upper bound was used to explore uncertainty effects. The derivation of these numbers is explained subsequently.

SPACE STATION PROGRAMS

COSTING GROUNDRULES/ASSUMPTIONS

ALL COSTS IN CONSTANT 1984 DOLLARS

ONE EQUIVALENT SET OF FLIGHT HARDWARE FOR GROUND TEST

STS COSTS ESTABLISHED AS UNCERTAINTY BAND:

- LOWER BOUND = CURRENT USER CHARGE OF $71M (1982) = $83M (1984)
- UPPER BOUND = EST. 1983-2000 CUM. AVG. COSTS = $117M (1984)

ONLY SPACE STATION MODULES ESTIMATED:

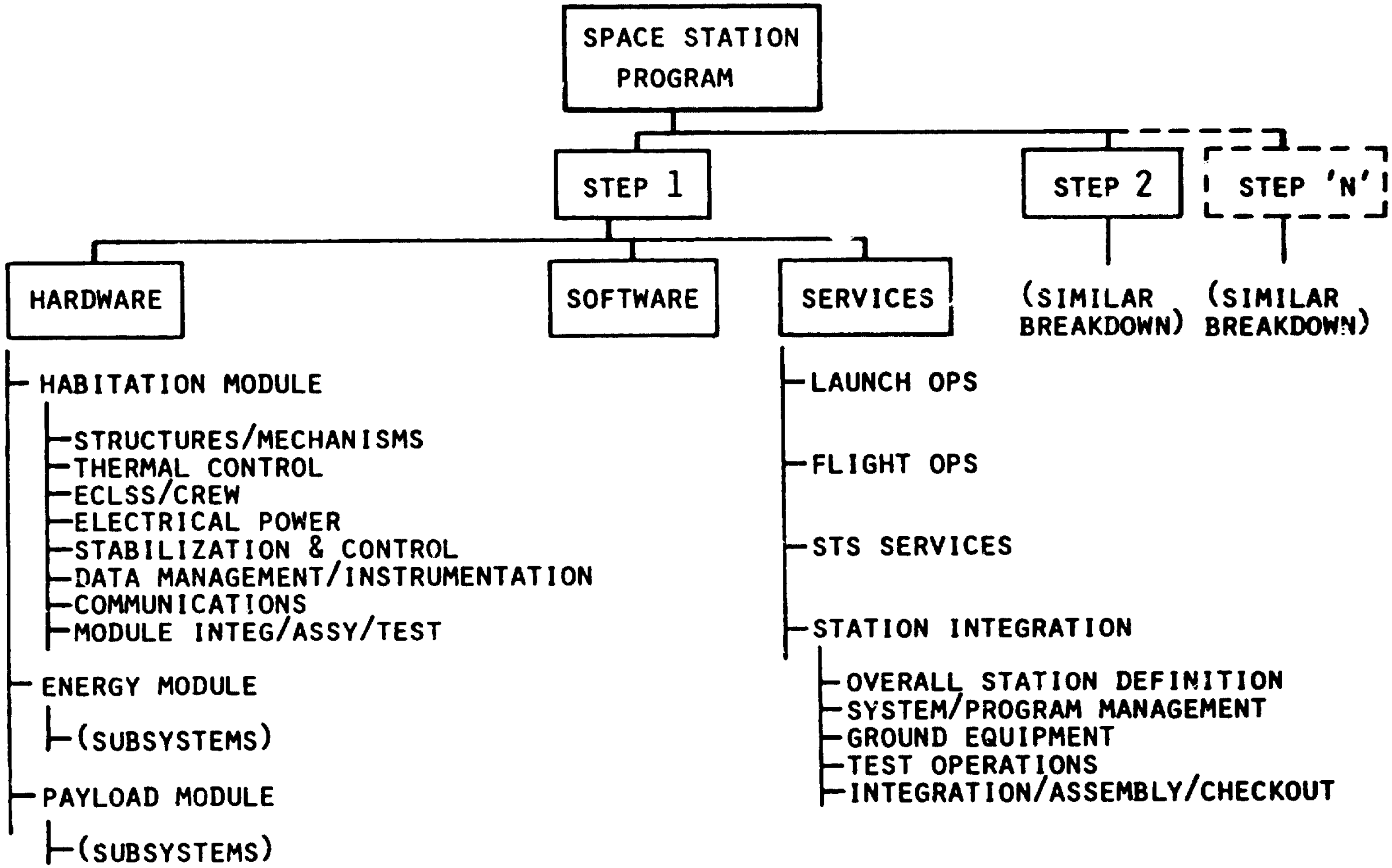
- NO OTV COSTS
- NO TMS COSTS
- NO PAYLOAD TRANSPORTATION/OPERATIONS

WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) used in formulating Space Station cost estimates is tailored to track evolutionary growth of Station architecture. The general arrangement is by evolutionary steps within the overall Space Station program. A standardized breakdown of hardware, software and services is replicated for every step; this conforms with the philosophy of the standard WBS promulgated by the Space Systems Cost Analysis Group. Building-block modules peculiar to each step are identified, and their subordinate subsystems are broken out. All hardware estimates were generated at subsystem level.

NOTE: For more information on the evolutionary space station growth steps refer to Attachment 2, Volume I, Task 3 Cost and Programmatic Concepts.

WORK BREAKDOWN STRUCTURE

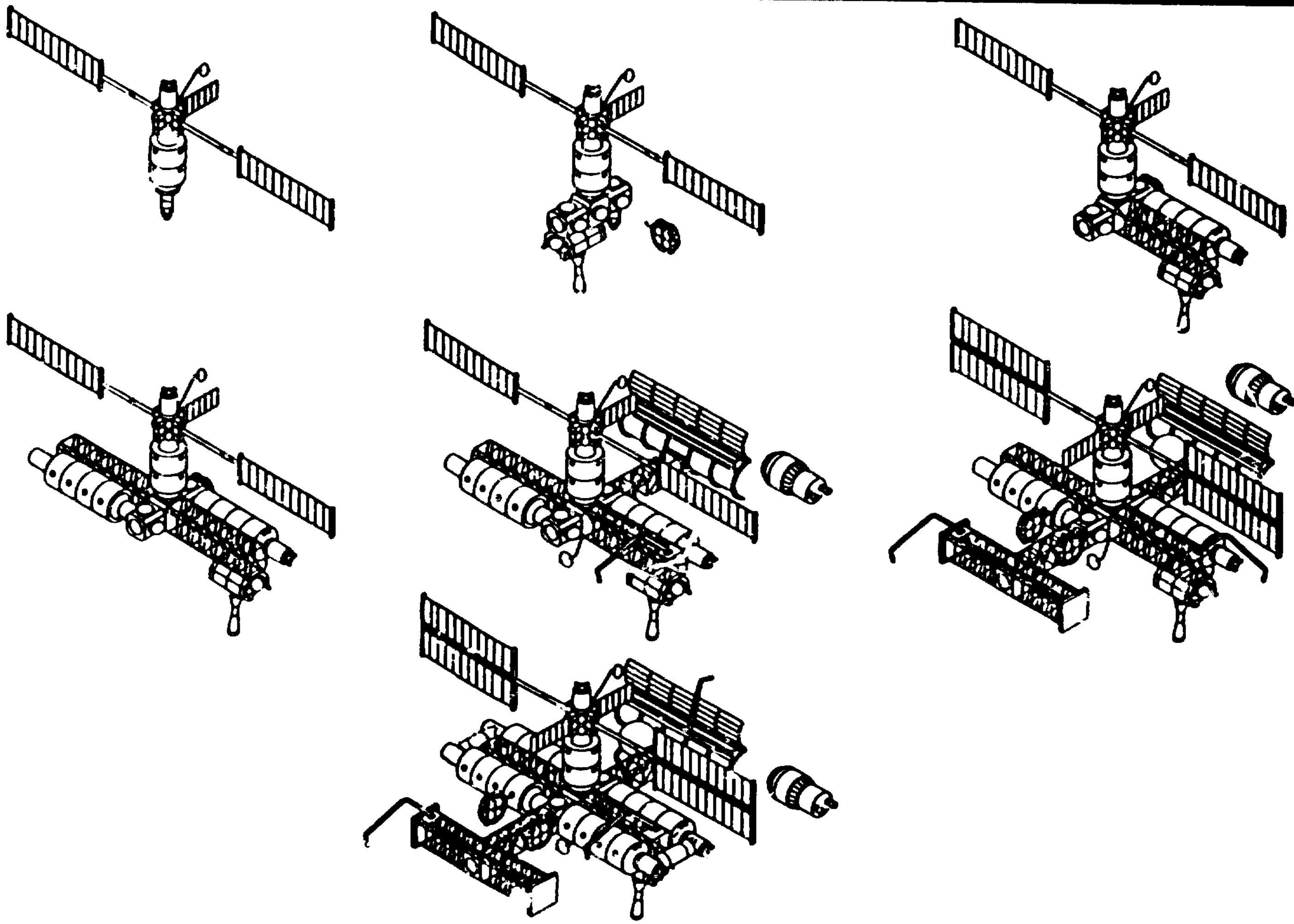


REFERENCE SPACE STATION BUILD UP

The attached sketches depict the evolutionary build up, through seven distinct phases, from a small 3 man/single module station to a 6 man all-embracing configuration. The build-up is arranged such that the evolution could be stopped at any phase and a useful facility remain operational. Twelve launches are required to place the facility on station not including approximately two resupply laurches per year.

SPACE STATION PROGRAMS

REFERENCE SPACE STATION BUILD UP



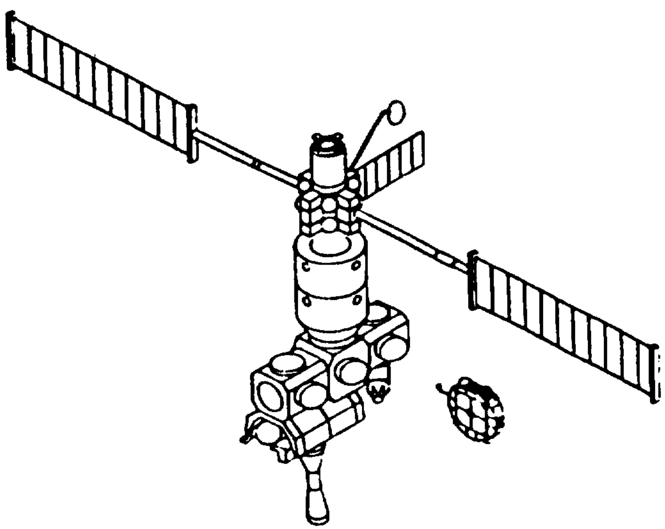
SPACE STATION MISSION ACCOMODATIONS

The following series of charts depicts the incremental growth of the reference space station from an initial capability baseline in January 1980 through seven phases of build-up to an ultimate capability in 1996. The evolving station capability to accomodate the mission scenarios which were developed and used in our study analysis is indicated for each capability increment.

As the station progresses to multi-mission capability, the mix of mission utilization becomes governed by specific experiment/payload requirements compatibility. For example human research experiments involving movement of personnel will tend to create motion in the station, which will interfer with other experiments that require accurate pointing stability. It is anticipated that scheduling and time sharing of the station facility can accommodate these operational constraints. Where contamination control and low g environment is required for extended time periods, the use of free flyers will permit multiple and simultaneous mission utilizaion.

Multiple mission use incompatibilities also exist for the station flight reference mode (inertial or attitude). Earth sensing missions such as the Earth Observation Facility (scenario 5) require an earth attitude flight mode whereas space sensing missions such as Space Observation Laboratory (scenario 10) require an inertial flight mode. It is assumed that techniques such as the use of instrument pointing systems for mounting the sensors or the use of rotating attachment joints to decouple the mission experiments (pallet mounted) could be used.

SPACE STATION MISSION ACCOMODATION
PHASE 2 JAN 1991



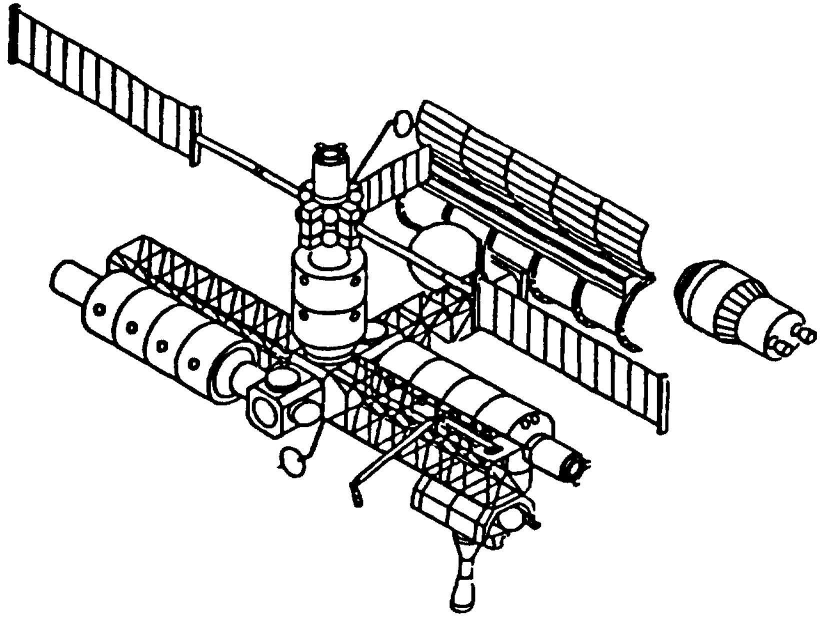
CAPABILITY	MISSION ACCOMODATION (STUDY SCENARIO NO)
• EARTH OBSERVATION FACILITY	(5)
• OCEAN OBSERVATORY LABORATORY	(11)
• SATELLITE SERVICING (MINIMUM)	(14)

STATION CAPABILITY ADDITION

- INTERCONNECT DOCKING MODULE
- PALLET
- TMS
- SPARES
- CONSUMABLES

SPACE STATION PROGRAMS

SPACE STATION MISSION ACCOMODATION
PHASE 5 JAN - APR 1993



MISSION ACCOMODATION

CAPABILITY	(STUDY SCENARIO NO)
• EARTH OBSERVATION FACILITY	(5)
• OCEAN OBSERVATORY LABORATORY	(11)
• SATELLITE SERVICING (MINIMUM)	(14)
• HUMAN RESEARCH LAB	(1)
• SPACE ENVIRONMENT FACILITY	(4)
• SPACE OBSERVATION LAB	(10)
• NON-HUMAN RESEARCH LAB	(2)
• MATERIAL PROCESSING LAB	(8)
• METEOROLOCIAL FACILITY (DETACHED FREE FLYER)	(7)

STATION CAPABILITY ADDITION

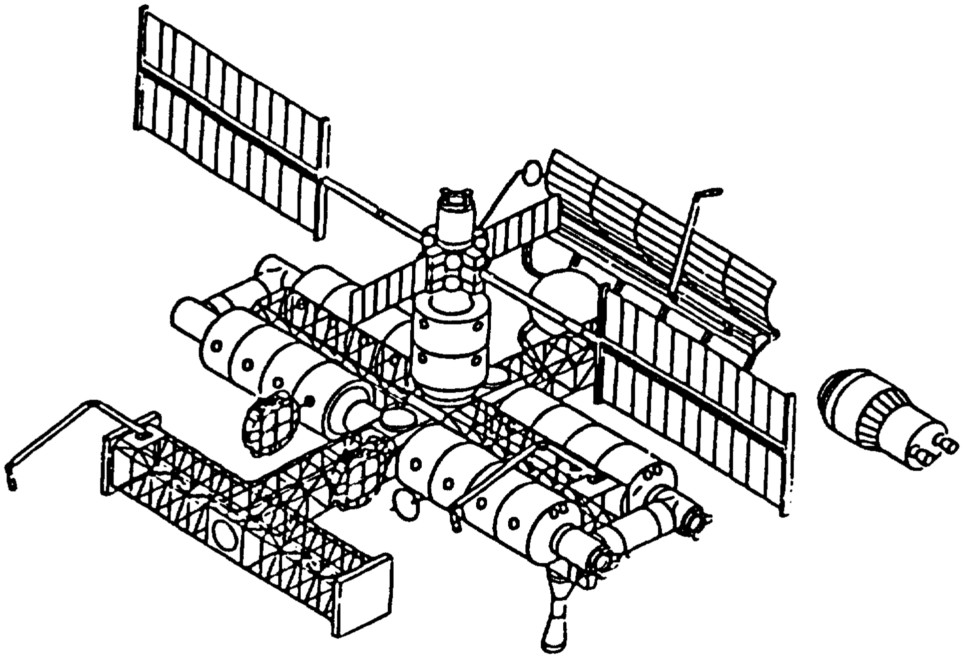
- CRYOGENIC OTV SUPPORT STRUCTURE
- OTV HANGAR
- FUEL STORAGE TANKS
- RMS
- TRACKS FOR RMS
- CRYOGENIC OTV
- ANTENNA DISH

ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

SPACE STATION PROGRAMS

SPACE STATION MISSION ACCOMODATION
PHASE 7 APR - JUL 1995



STATION CAPABILITY ADDITION

- GENERAL PURPOSE RESEARCH MODULE
- MATERIALS PROCESSING LABORATORY MODULE
- POWER MAY BE INCREASED DEPENDING ON USER DEMAND TO 100+ kW (CONSIDER NUC. SOURCE)

MISSION ACCOMODATION

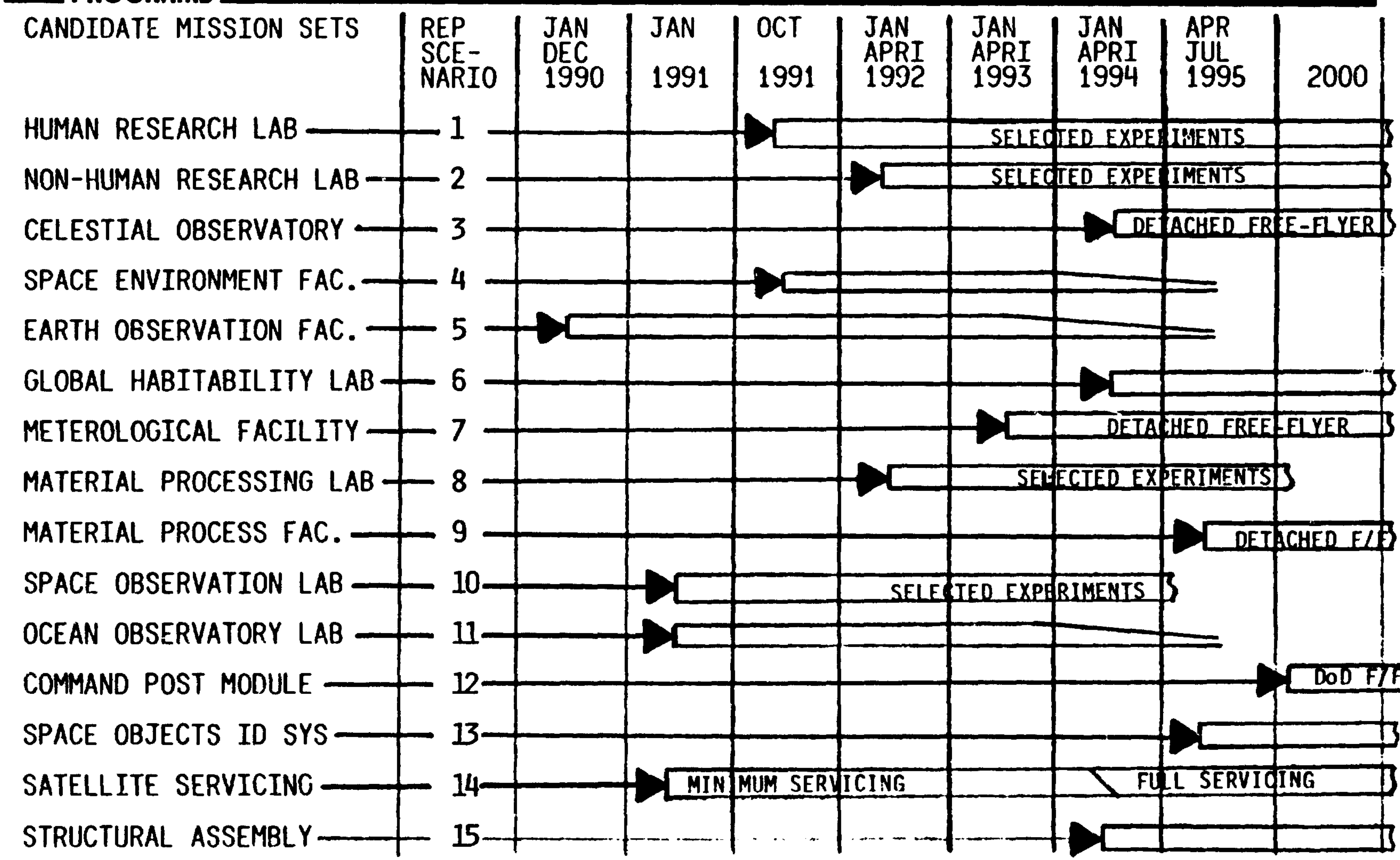
CAPABILITY	(STUDY SCENARIO NO)
• EARTH OBSERVATION FAC.	(5)
• OCEAN OBSERVATORY LAB	(11)
• SATELLITE SERVICING (FULL CAPABILITY)	(14)
• HUMAN RESEARCH LAB	(1)
• SPACE ENVIRONMENT FAC.	(4)
• SPACE OBSERVATION LAB	(10)
• NON-HUMAN RESEARCH LAB	(2)
• MATERIAL PROCESSING LAB	(8)
• METEOROLOCIAL FACILITY (DETACHED FREE FLYER)	(7)
• CELESTIAL OBSERVATORY (DETACHED FREE FLYER)	(3)
• GLOBAL HABITABILITY LAB	(6)
• STRUCTURAL ASSEMBLY	(15)
• MAT'LS PROCESSING FAC. (DETACHED FREE FLYER)	(9)
• SPACE OBJECTS ID SYS.	(13)

Lockheed

SPACE STATICN MISSION UTILIZATION

The utilization of the reference space station by the reference mission scenarios used in this study is shown on the facing page. As shown here, the utilization manifest and station loading is based primarily on station performance support capability without regard to work task scheduling, since no task time line analyses were performed on the mission scenarios. In order to substantiate this forecast mission use, each scenario needs to be evaluated for task, time and detail support requirements. This should be performed in further studies.

SPACE STATION MISSION UTILIZATION



ORIGINAL PAGE IS OF POOR QUALITY

REFERENCE SPACE STATION BUILD-UP LAUNCHES

A time phased evolutionary build-up of the all-up complex is shown here, the weights associated with each launch, the major elements being deployed, and launch date are included.

A detailed weight estimate for each launch is included in the programmatics study, Attachment 1, Volume IV.

SPACE STATION PROGRAMS

ORIGINAL PAGE IS
OF POOR QUALITY

REFERENCE STATION BUILD UP LAUNCHES

		STEP 1	STEP 2	STEP 3		STEP 4		STEP 5		STEP 6		STEP 7	
	LAUNCH DATE	JAN '90	JAN '91	JULY '91	OCT '91	JAN '92	APR '92	JAN '93	MAR '93	JAN '94	APR '94	JAN '95	APR '95
	LAUNCH NO.	1	2	3	4	5	6	7	8	9	10	11	12
PRIMARY ELEMENTS	3 MAN HAB	28.15											
	ENERGY MODULE	17.00											
	SENSOR MODULE	4.90											
	INTERCONNECT MODULE		10.35										
	TMS		7.83										
	CENTER STRUCT #1			26.4									
	HABITATION MODULE				30.4								
	AIR LOCK				4.0								
	CENTER STRUCT #2					21.4							
	SENSOR LAB						32.55						
	AIRLOCK MODULE						4.00						
	CRYO OTV SUPPT.							20.2					
	CRYO HANGAR							15.9					
	RMS							1.2					
	OTV TANKAGE								7.0				
	OTV VEHICLE								53.2				
	COMM ANT.								.4				
	25 Kw PWR.									17.8			
	TMS SUPT.MOD									22.9			
	TMS									7.8			
	SPACECRAFT SERVICE										20.1		
	RMS										1.2		
	STORABLE PROPS.										10.0		
	ATT.CONT.MODULES										2.0		
	G.P.RESEARCH											39.8	
	RMS											1.2	
	MATL.PROC.MOD.												44.4
	RMS (2)												2.4
	SHUTTLE ITEMS	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.0	4.0	3.0	3.0	3.0
	TOTAL LAUNCH V/H	54.05	30.18	30.4	38.4	25.4	40.55	41.3	62.6	52.5	36.3	44.0	49.8

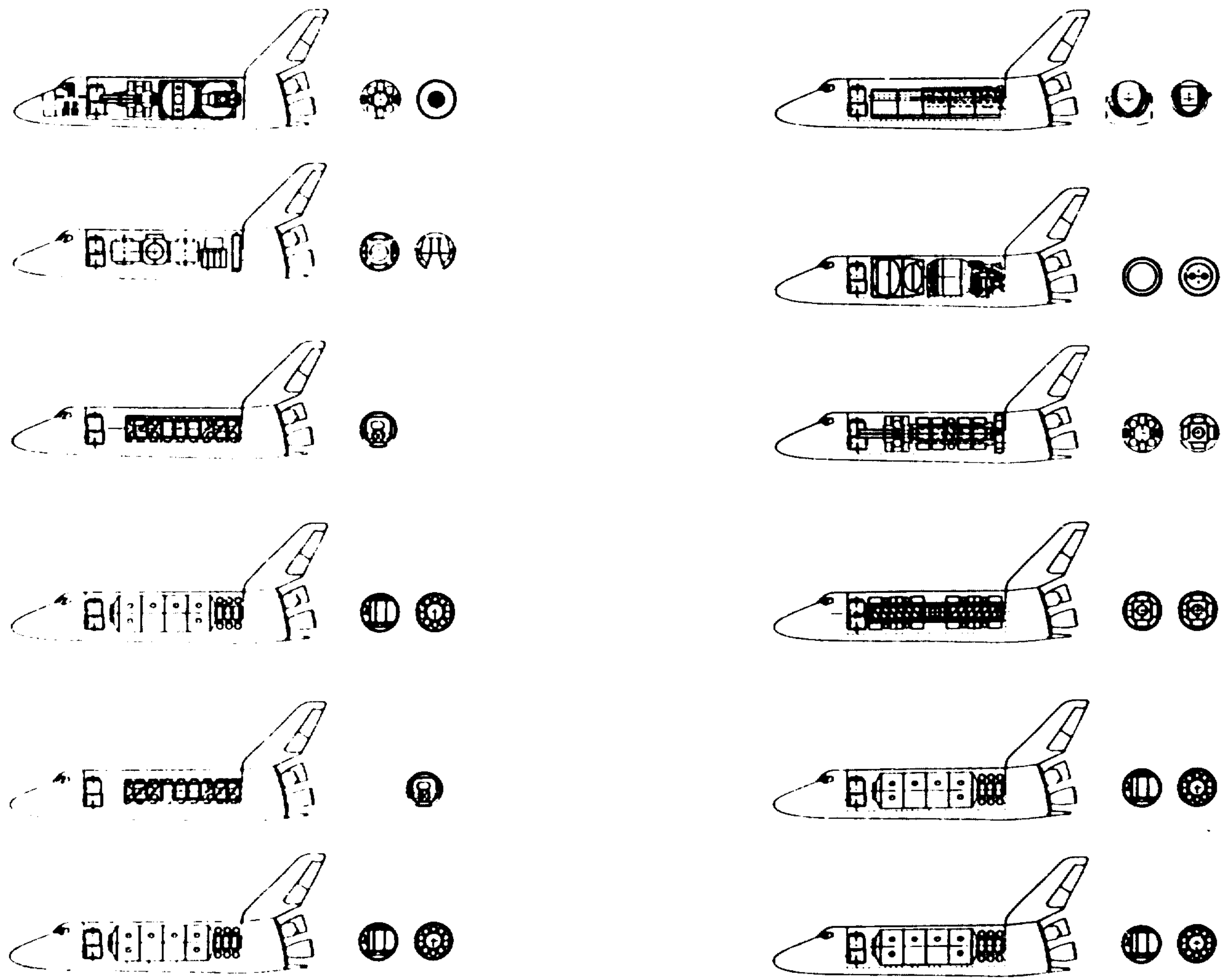
Lockheed

REFERENCE STATION LAUNCH CONFIGURATIONS

The shuttle payload bay is fully occupied for almost all twelve build-up launches as can be seen from this drawing, however, although the available volume is effectively used, the total weight capability is not as can be seen on the preceding chart. This excess capability could be used, of course, for experiments, consumables, contingency etc.

SPACE STATION PROGRAMS

REFERENCE SPACE STATION — LAUNCH CONFIGURATIONS



ORIGINAL PAGE IS OF POOR QUALITY

Lockheed

PROGRAM FUNDING PROFILE

This figure shows the funding levels for development, and operation of the Lockheed reference Space Station architecture. Costs are in millions of constant 1984 dollars. This is a composite chart that sums the funding levels for each of the seven evolutionary steps, plus one year of steady-state operations for the all-up configurations. The one year of operations (ending December 1996) is funded at $580 million.

The assumed start of the program is October 1984 (the beginning of fiscal year 1985). This date has no significance other than in terms of the arbitrary January 1990 first-launch data shown in the LMSC evolutionary scenario. All spans and funding should be thought of as 'time zero' i.e., years from program start. In these terms, the peak funding of just under $1.5 billion occurs in the sixth and seventh years after go-ahead.

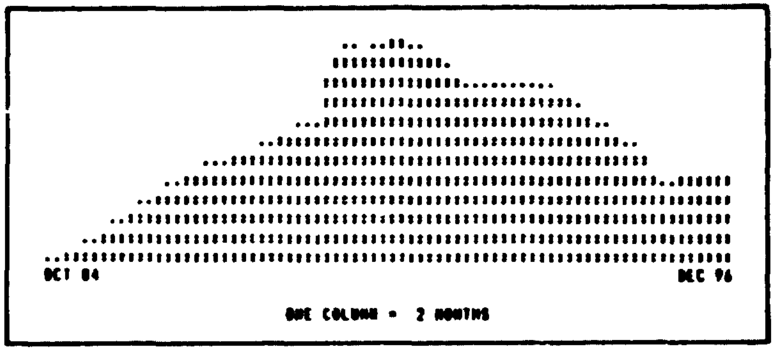
SPACE STATION PROGRAMS

PROGRAM FUNDING PROFILE

YEARLY EXPENDITURE SUMMARY

COSTS IN DOLLARS — 1 JAN 84 UNITS

PERIOD ENDING	PER CENT COMPLETE	EXPENDITURES FOR PERIOD TOTAL	EXPENDITURES FOR PERIOD %	CUMULATIVE EXPENDITURES TOTAL	CUMULATIVE EXPENDITURES %
DEC 84	0.0	1.0	0.0	1.0	0.0
DEC 85	1.0	102.7	1.0	103.7	1.0
DEC 86	4.5	369.6	3.5	473.3	4.5
DEC 87	10.3	605.6	5.8	1078.9	10.3
DEC 88	17.6	752.9	7.2	1831.7	17.6
DEC 89	27.1	999.8	9.6	2831.5	27.1
DEC 90	41.1	1455.7	14.0	4287.3	41.1
DEC 91	54.9	1445.9	13.9	5733.2	54.9
DEC 92	66.7	1226.2	11.8	6959.4	66.7
DEC 93	78.1	1187.8	11.4	8147.2	78.1
DEC 94	87.8	1015.4	9.7	9162.6	87.8
DEC 95	94.4	691.7	6.6	9854.2	94.4
DEC 96	100.0	580.2	5.6	10434.4	100.0



ORIGINAL PAGE IS OF POOR QUALITY

Econ — Lockheed

SPACE STATION PROGRAM COSTS

This figure summarizes the incremental buildup of costs needed to implement each step of the reference Lockheed Space Station architecture. Step 1 deploys a Station that represents an initial operational capability at a cost of $2.8 billion. Steps 2 through 4 augment this capability in increments for an added cost of $2.8 billion ($5.6 billion cumulative). Step 5 adds OTV servicing capability for an added cost of $1.4 billion ($7.0 billion cumulative). Step 6 adds spacecraft servicing capability at an added cost of $1.3 billion ($8.3 billion cumulative). Step 7 completes the configuration and adds materials processing capability for an added $1.6 billion ($9.9 billion cumulative).

Acquisition cost drivers for the Space Station include test article philosophy (photoflight versus one or more dedicated test vehicles); relative state of the art; and inheritance (for both hardware and software). Operational cost drivers include STS resupply intervals and STS price per flight. For example, applying the upper-bound STS price per flight of $117 million would increse the operations costs shown here by $850 million, an increase of more than 25 percent.

The influence of Space Station autonomy on life cycle cost is not completely clear. The most likely area for savings due to autonomy is in the operational cost for NCC operations, which is estimated at $50.2 million per year. However, any savings must be traded against the added acquisition costs needed to achieve autonomy.

SPACE STATION PROGRAMS

SPACE STATION PROGRAM COSTS
($ MILLION, 1984)

	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	TOTAL
DDT & E	1938	129	556	392	631	321	534	4501
PRODUCTION	392	60	289	316	276	327	564	2224
OPERATIONS	511	255	255	511	511	639	456	3138
TOTAL	2841	444	1100	1219	1418	1287	1554	9863

OBSERVATIONS ON COST AND SCHEDULE

The LMSC evolutionary architecture defined in this study provides an early operational capability yet grows to provide services that bring the national Space Transporation to its full original promise. Moreover, this capability is added in increments that keep annual outlay within reasonable bounds.

SPACE STATION PROGRAMS

OBSERVATIONS ON COST AND SCHEDULE

FOR THE REFERENCE LMSC SPACE STATION EVOLUTION:

- AN INITIAL CAPABILITY (STEP 1) CAN BE IMPLEMENTED FOR LESS THAN $4 BILLION (1984)
- FULL CAPABILITY (STEPS 1-7) CAN BE ATTAINED FOR LESS THAN $10 BILLION

FOR A FY1985 START, THE FUNDING LEVELS ARE:

- PEAK FUNDING LESS THAN $1.5 BILLION
- PEAK IN 1990-1991

DESIGN-TO-LIFE-CYCLE-COST CONSIDERATIONS:

- BEST PAYOFF IS IN REDUCING RESUPPLY COSTS ($83M - 117M/FLIGHT)
- THESE SAVINGS CAN OFFSET HIGHER SUBSYSTEM DEVELOPMENT COSTS

SPACE STATION PROGRAMS

CONCLUSIONS

Lockheed

SPACE STATION PROGRAMS

CONCLUSIONS

- PERSONAL CONTACT USER ALIGNMENT PLAN SUCCESSFUL - SHOULD BE CONTINUED TO PRESENT MOMENTUM LOSS
- FOREIGN INTERESTS EAGER TO PARTICIPATE - COOPERATE APPROACH BENEFICIAL
- SPACE STATION WILL ADVANCE SCIENCE AND APPLICATION NOW CONSTRAINED BY STS LIMITATIONS
  - LONGER TERM
  - LOWER COST
- USA MUST ACCELERATE HIGH TECHNOLOGY TO WITHSTAND FOREIGN COMPETITION
- OTV's ESSENTIAL TO SYSTEM OPERATION
  - EXISTING OTV's SUPPORT SOME MISSIONS
  - ADVANCED OTV's WILL EXPAND CAPABILITY FOR REMOTE OPERATIONS
- INITIAL STATION CHARACTERIZED BY SIMPLICITY

o 28.5° INC	OPERATIONAL STEP 4:
o 15 kW POWER	25kW - 200kW+
o 2 - 3 PERSON	4 - 16 PERSON
o SINGLE SHUTTLE LAUNCH	

Lockheed

LOCKHEED ASSESSMENT OF SPACE STATION NEED

A space station should be initiated now for initial operations in the early 1990's. By the latter half of the 90's launch costs can be expected to be reasonable, and manned space operations will be routine, efficient, and essential to the well being of the United States.

LOCKHEED ASSESSMENT OF SPACE STATION NEED

THE CAPABILITY FOR MANNED SPACE OPERATIONS IS ESSENTIAL TO THE WELL BEING OF THE UNITED STATES

A SPACE STATION PROGRAM SHOULD BE INITIATED NOW